# Current Research on Food Engineering and Science

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# Preface

Food science is becoming more and more important in a world of changing social dynamics, environmental imperatives and increasing health awareness. This book aims to provide readers with both scientific and practical information by addressing important topics in the food sector. Organised under the headings of "Herbs and Spices", "Antioxidants As a Food Additives", " Ohmic Cooking in Food Technology", "Sustainable Foods and Consumption", "Food Safety, Food Adulteration and Fraud" and "Sourdough Fermentation and the Microbiome", this work provides an in-depth look at the complexities and potential solutions of the food industry. Herbs and spices have a critical role in the food industry as both flavour and health ingredients. These natural additives not only enrich the taste and aroma of foods, but also offer health benefits through their antioxidant properties. Ohmic cooking is a revolutionary approach in food technology. It uses electric current to cook food more uniformly, which helps to preserve its nutritional value. This innovative technology is also important for improving energy efficiency and minimising food waste. Sustainable food and consumption involves the interaction of vital issues such as climate change, environmental degradation and public health. Improving food systems helps both to improve nutritional security and to protect ecosystems. Work on sustainable food and consumption has profound impacts not only on individual health, but also on community and environmental health. The integration of education, awareness raising and policy development processes plays a fundamental role in building healthy and sustainable food systems. Food safety is one of the most important issues of our time. Food adulteration and fraud is one of the biggest threats in this area and can endanger the health of consumers. Establishing high safety standards in food production is critical for establishing social trust. The components of sourdough products have positive effects on intestinal health and improve general health status. In this context, the importance of traditional food processing methods in the context of contemporary nutrition is increasing. This book aims to convey to the reader the importance of health, safety and sustainability by analysing important issues in the food industry.

# Contents

Chapter 1

# Herbs and Spices in Food Industry

**Gülten Şekeroğlu**[1]

**Ahmet Kaya**[2]

**Abstract**

Herbs and spices are aromatic products, either fresh or dried, derived from plants, utilized to enhance the flavor of both plant and animal-based foods. Herbs are typically derived from the leaves of plants, whereas spices originate from seeds, roots, bark, fruits, berries, arils, pods, and flowers. Herbs and spices have played a fundamental role in the evolution of global food cultures. Beyond culinary applications, they hold religious, economic, medicinal, and political significance. Their trade shaped empires, and their aromatic and preservative qualities enriched home cooking and industrial food production deeply. In ancient civilizations, spices and herbs were regarded as superfoods endowed with mythical medicinal properties.

## 1. Introduction

The Codex Alimentarius defines spices as aromatic seeds, buds, roots, rhizomes, bark, pods, flowers or their components, berries, or other fruits from various plants, utilized in modest amounts to enhance the flavor of foods (CODEX, 2015). They are predominantly utilized in their dried form as seasonings. It is logical to categorize all plants whose leaves are utilized for their aromatic qualities. Herbs may be utilized fresh in domestic kitchens or restaurants, where their delicate aromatic qualities are optimally preserved; however, the predominant portion of the market relies on dried herbs. Herbs primarily pertain to the Lamiaceae and Umbelliferae families (Lai & Roy, 2004; Vázquez-Fresno et al., 2019).

Spices and herbs have been accessible to humans for an extensive period. Recent archaeological discoveries in the Swiss Jura mountains have revealed

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fennel seeds from the Neolithic period (5000 B.C.). Chile peppers, a fundamental seasoning in contemporary cuisines, originated in the Andes and were utilized as early as 10,000 years ago. Archaeological excavations in Mexico have uncovered chile pepper remnants that date to 7000 B.C (Raghavan, 2006).

Herbs and spices have traditionally functioned as crucial flavoring agents and important food preservatives owing to their inherent phytochemical properties (Alieozaman et al., 2024; Norris & Dahl, 2013). Their incorporation into culinary traditions spans millennia, with evidence indicating that spices like pepper and cinnamon were exchanged along the Spice Road and regarded as currency. The consistent rise in global production and consumption of herbs and spices over the last twenty years underscores their sustainable significance in modern diets (Blanton, 2020).

Since the early ages, the main trade route from South Asia to Europe is known as the 'Spice Road'. The spice route in history encapsulates a multifaceted and transformative trade network. It was not merely a passage for spices but a dynamic system that stimulated economic prosperity, fostered intercultural dialogue, and reshaped global political and social structures over many centuries (Torr, 2021; Xu, 2021;Winter, 2021).

Consumer demand for dried products that retain most of the original characteristics of fresh products is increasing. To meet this consumer demand, it is essential to consider drying methods that preserve the taste, aroma, color, nutrients, and texture of the plants to the greatest extent possible (Crivelli et al. 2002; Hossain et al., 2022). In addition to quality concerns, drying efficiency is a crucial factor for evaluating drying performance, encompassing total energy consumption, drying duration, drying rate, and related metrics.

Numerous conventional drying techniques have been employed in the processing of herbs and spices, including solar drying (Özcan et al., 2005), hot air drying (Demiray & Tulek, 2014), vacuum drying (Wang et al. 2018), and microwave drying (Arslan et al. 2010). Nonetheless, nearly all these methods necessitate prolonged drying times and substantial energy expenditure, consequently yielding processed samples of subpar quality (Moses et al. 2014; Karam et al., 2016; Hossain et al., 2022). They must be processed under appropriate drying conditions due to their high sensitivity to heat.

## 1.1.Herbs and Spices

### 1.1.1.Herbs

Herbs are fragrant components of a plant utilized for seasoning, fragrance, medicinal purposes, or ceremonial practices (D. Ibáñez & Amparo Blázquez Ferrer, 2019). Commonly utilized herbs encompass basil, bay, borage, chamomile, chervil, dill, fennel, garlic, mint or peppermint, oregano, parsley, rosemary, sage, tarragon, and thyme. Herbs may originate from leaves, flowers, or stems and can be utilized in either dried or fresh forms. Certain herbs, such as basil, are prevalent in Asian culinary practices. Herbs differ from spices as spices originate from various parts of a plant. Dried herbs or whole leaves frequently possess a distinctive flavor due to the presence of essential oils.

Fresh herbs are also known as culinary herbs. They possess a significant water content, and their aromatic qualities are most pronounced when fresh. Certain herbs, such as parsley, chervil, and chives, endure freezing effectively when minced, preserving their color and aroma, thereby allowing for their continued domestic utilization during winter. Nonetheless, their industrial application is confined to restaurants. Oregano and thyme both possess elements that enhance their flavors. Herbs are utilized to enhance the flavor of numerous dishes. In Asia, fresh herbs are predominantly utilized in culinary practices, whereas in the West, dried herbs are more prevalent Kumar Saini et al., 2021. Certain plants, including rosemary and bay, are predominantly utilized in their desiccated state akin to spices. Fresh herbs are typically incorporated at the final moment or immediately prior to serving to preserve the volatile oils. These oils enhance the flavor and fragrance of the food. The desiccated and pulverized form of mint is prevalent in mint tea and occasionally utilized in lamb dishes. Dried herb powders are similarly incorporated into the majority of curries (Kumar Saini et al., 2021).

### 1.1.2.Spices

The Food and Drug Administration (FDA) defines spices as "aromatic vegetable substances, in whole, broken, or ground form, whose primary purpose in food is seasoning rather than nutrition" (Vázquez-Fresno et al., 2019). The term spice originates from the Latin word 'species,' which denotes plants utilized for both medicinal and flavoring purposes.

Spices are generally used in foods to give flavour and aroma, and they are also used to prevent food spoilage because they contain antioxidant substances in their structure. They are also effective as antimicrobial agents in preventing the development of microorganisms due to the essential oils they contain. Spices are also widely used in the food, pharmaceutical and cosmetic industries due to their essential oils and components.

Spices are the desiccated components of plants primarily utilized for enhancing the flavor of food, particularly in cuisines characterized by robust flavors, as well as in sauces, gravies, pickles, pastes, curry powders, and preparations of fish and meat (Ayoade et al., 2023). They are utilized in medical applications and have a historical precedent for preserving meat, augmenting consumer appeal, and functioning as antioxidants. Whole spices possess significant health benefits, including antioxidant, antimicrobial, antifungal, anti-tumor, anti-inflammatory, and antidiabetic properties. They are recognized for alleviating unpleasant food odors, enhancing thirst, salivation, and appetite, and are deemed carminative. Spices such as clove, nutmeg, cumin, and saffron are recognized for their stimulatory qualities (Puvača, 2022; Dhulipalla et al., 2023; Modupalli et al., 2022). Spice tea is typically prepared using spices like cardamom, ginger, and cinnamon to alleviate cough, cold, and flu symptoms

Spices contain mineral elements that support normal bodily functions and promote bone health. Calcium, phosphorus, potassium, magnesium, zinc, and sodium are essential in regulating blood pressure, oxidative stress, energy production, and metabolic functions. The presence of sodium and calcium in specific spices may aid in the prevention of kidney stones. Iron present in spices is crucial for hemoglobin formation, red blood cell production, and DNA synthesis. Iron supplementation results in weight gain and enhanced hematological parameters (Ayoade et al., 2023).

The human tongue is capable of perceiving five fundamental tastes: sweet, sour, salty, bitter, and umami (savory). Spices can affect these tastes in multiple ways, not only by directly stimulating taste buds but also through their aroma, which can modify flavor perception. These compounds are released when a spice is ground, cooked, or chewed (Raghavan, 2006).

Spices give characterizing tastes and aromas (Table 1). They give six basic taste perceptions: sweet, salty, spicy, bitter, sour, and hot. The other descriptive terms include pungent, umami (brothy, MSG, or soy-sauce-like), cooling, and floral, earthy, woody, or green. Most spices have multiple flavor profiles. Fennel has sweet, bitter, and fruity notes; tamarind exhibits fruity and sour notes; whereas cardamom features sweet and woody notes (Raghavan, 2006).

***Table 1. The Sensory Characteristics of Spices (Raghavan, 2006)***

| Sensory characteristic | Spices or other flavourings |
|---|---|
| Bitter | Clove, Fenugreek, Thyme |
| Cooling | Spearmint,Basil, Anise |
| Earthy | Turmeric, Saffron, Turmeric, |
| Floral | Lavender, Lemongrass, Sweet basil, |
| Fruity | Coriander, Tamarind, Star anise |
| Herbaceous | Fennel, Rosemary, Parsley |
| Hot | Mustard, Pepper, Chile peppers |
| Nutty | Cumin seed, Sesame seed, Mustard seed |
| Piney | Rosemary, Thyme, Bay leaf, |
| Spicy | Ginger, Cumin,Ginger, |
| Sour | Sumac, Kokum, Caper |
| Sulfury | Chives, Garlic, Onion |
| Sweet | Cinnamon, Anise, |
| Woody | Juniper, Cassia, Rosemary |

Spices are utilized in various forms. Certain varieties are utilized as components in curry powder, while others are employed as toppings for fruits, nuts, and pastries. Certain spices with distinct characteristics impart varied flavors; for instance, caraway and poppy seeds provide sweetness, while pepper contributes heat to dishes. Mint and basil represent a distinct category of herbs that impart a cooling effect to chilled dishes. Spices are frequently boiled to extract their flavor while discarding the solid remnants. Saffron is the most expensive spice (Kothari et al.2021; Álvarez et al.2024).

### 1.2.Chemistry and composition of herbs and spices

Herbs and spices represent a remarkably diverse category of plant-derived substances whose composition and chemistry have been extensively studied. Their chemical composition consists of various bioactive compounds, such as polyphenols, flavonoids, essential oils, terpenoids, and trace elements, all of which contribute to their distinct sensory attributes and health advantages (Shan et al., 2005).

The overall flavor, taste, aroma, texture, or color imparted by a spice to food or beverage dictates its efficacy in a recipe or formulation. Each spice or flavoring comprises dominant chemical constituents that produce these sensory attributes. The chemical compounds of a spice can impart flavors ranging from mild to strong. The composition of these chemical compounds imparts a spice its distinctive flavor profile (Raghavan, 2006).

Polyphenols and flavonoids present in herbs and spices are essential for their antioxidant activity and potential disease-modifying effects. Phenolic diterpenes, including carnosic acid, carnosol, and rosmanol—found in *Labiatae* family spices such as rosemary and sage—substantially enhance the antioxidant capacity of these plants (Shan et al., 2005). Simultaneously, the analysis conducted by Yashin et al. (2017) emphasize the antioxidant properties of spices, highlighting the function of polyphenols in neutralizing free radicals and safeguarding against lipid peroxidation. Supporting these findings, Opara and Chohan (2014) highlighted that the various polyphenolic compounds may function synergistically, indicating that their bioactive properties could manifest even at the low concentrations commonly found in herbs and spices.

Besides polyphenols, herbs and spices are distinguished by volatile essential oils and terpenoids, which contribute to their unique aromas and flavor profiles. The composition of these essential oils is known to fluctuate based on factors including geographical origin, plant variety, age, and processing techniques (Sospedra et al., 2010). Essential oils not only enhance flavor but also exhibit antimicrobial properties, as evidenced by studies demonstrating inhibitory effects against pathogenic bacteria (Vitullo et al., 2011). The interaction between these volatile compounds and other antioxidants is essential for culinary purposes and the modulation of gut microbiota, as polyphenols from herbs and spices have been demonstrated to promote a healthy intestinal environment (Wilson et al., 2024).

Moreover, specific herbs and spices possess unique compounds like kynurenic acid (KYNA), with significant concentration variability across various species. Turski et al. (2015) indicated that basil possessed KYNA concentrations approximately 140 times greater than those present in black pepper, underscoring the diverse array of bioactive chemical compounds inherent to these plants. These findings elucidate the intricate chemical ecology of herbs and spices, wherein minor constituents may exert considerable physiological effects.

Table 2 summarizes the primary flavor compounds present in the principal herbs and spices utilized by the food industry. Certain flavor compounds in spices are water-soluble, while many others are soluble in oil or fat. Typically, the flavors of a spice require time to permeate the food; therefore, spices are incorporated early in the cooking process. This differs from herbs, which are typically incorporated later in the preparation process (Sharangi et al.,2019).

*Table 2. Main Flavor Compounds in Herbs and Spices (Sharangi et al.,2019)*

| Type of herbs and spices | Flavor compound |
|---|---|
| Allspice | Eugenol, caryophyllene |
| Anise | (E)-anethole, methyl chavicol |
| Basil, sweet | Methylchavicol, linalool, methyl eugenol |
| Bay laurel | 1, 8-cineole |
| Black pepper | Piperine, S-3-Carene, β-caryophyllene |
| Caraway | d-carvone, carone derivatives |
| Cinnamon, cassia | Cinnamaldehyde, eugenol |
| Chili | Capsaicin, dihydro capsaicin |
| Coriander | d-linalool, C10-C14–2- alkenals |
| Cumin | Cuminaldehyde |
| Fennel | (E)-anethole, fenchone |
| Ginger | Gingerol, Shogaol, geranial |
| Marjoram | c- and t-sabinene hydrates, terpinen-4-ol |
| Mustard | Allyl isothiocynate |
| Origanum, Oregano | Carvacrol, thymol |
| Parsley | Apiol |
| Peppermint | 1-menthol, menthone, menthfuran |
| Rosemary | Verbenone, 1–8-cineole, camphor, linanool |
| Saffron | Safranal |
| Sage, Clary | Salvial-4 (14)-en-1-one, Linalool |
| Thyme | Thymol, carvacrol |
| Turmeric | Turmerone, Zingeberene, 1,8-cineole |
| Vanilla | Vanillin |

## 1.3.Health benefits and nutritional value of herbs and spices

Spices and dried herbs are commonly consumed items integral to the diets of individuals worldwide. Fresh aromatic spices, spice extracts, and spice oils are utilized in various culinary preparations, particularly in ethnic cuisine. Mexico, India, and numerous Latin American and Asian nations are renowned for their abundant traditions of spices and dried herbs. In recent years, there has been a significant rise in the production value of fresh spices and dried herbs, accompanied by rapid expansion in the global trade of these commodities. Herbs and spices, although ingested in minimal amounts, have garnered considerable interest due to their rich bioactive compounds that provide various health advantages and improve nutritional quality (Rakhi et al., 2018; Tapsell et al., 2006). They are abundant in phytochemicals, including polyphenols, flavonoids, essential oils, and vitamins, which contribute to a wide range of biological activities.

Data-driven analyses demonstrate that spice consumption correlates with antimicrobial and anti-infective properties, alongside a reduced risk of various chronic diseases (Rakhi et al., 2018; Tapsell et al., 2006). This bioactivity is primarily ascribed to compounds that mitigate oxidative stress and inflammation, processes associated with numerous degenerative conditions (Serafini & Peluso, 2017).

The antioxidant capacity of herbs and spices is among their most significant nutritional attributes. Research has shown that numerous prevalent spices contain significant amounts of phenolic compounds and flavonoids, which mitigate oxidative damage in biological systems and enhance food stability by inhibiting lipid peroxidation (Kähkönen et al., 1999). Thyme, characterized by its significant thymol and carvacrol concentrations, exhibits strong antioxidant and antimicrobial properties, thereby fulfilling dual functions in food preservation and health enhancement (Kähkönen et al., 1999; Witkowska et al., 2013). Culinary research indicates that the effectiveness of bioactive compounds is affected by cooking conditions; moderate heat can preserve or enhance the availability of antioxidants in herbs and spices, while excessive temperatures may degrade these beneficial components (Aphrodite et al., 2021).

In addition to offering antioxidant advantages, herbs and spices enhance metabolic health by influencing the gut microbiota. Recent evidence indicates that specific spice extracts possess prebiotic properties, thereby fostering a balanced gut microbiota, which is crucial for comprehensive digestive and immune health (Lu et al., 2017). The interplay between dietary elements and gut microbiota enhances the functional advantages of integrating herbs and spices into the diet, presenting a promising supplementary approach for the prevention of diet-related diseases (Serafini & Peluso, 2017).

Herbs and spices have long been acknowledged for their capacity to enhance the sensory attributes of food, as well as for providing substantial health benefits that surpass fundamental nutrition. Their concentrated profiles of bioactive compounds—comprising polyphenols, flavonoids, essential oils, vitamins, and minerals—exhibit a variety of pharmacological activities, including antioxidant, anti-inflammatory, antimicrobial, anti-diabetic, cardioprotective, and anticancer effects (Spence, 2024; Jiang, 2019; Khanal et al., 2021).

The nutritional value of herbs and spices primarily stems from their elevated levels of phytochemicals, which function as powerful antioxidants. These compounds can mitigate the harmful effects of oxidative stress by neutralizing reactive oxygen species and binding pro-oxidant metals. Research has shown that spices like cinnamon, clove, and turmeric are abundant in polyphenols and flavonoids, which aid in reducing cholesterol levels and regulating blood glucose (Jiang, 2019; Khanal et al. 2021; Paswan et al. 2021). Moreover, incorporating these ingredients into the diet has been demonstrated to interfere with pathways that contribute to chronic inflammation, a significant factor in the onset of cardiovascular diseases and other metabolic disorders (Spence, 2024; Khanal et al., 2021).

In addition to their potent antioxidant properties, herbs and spices offer multifaceted health benefits via various mechanistic pathways. Their bioactive compounds can influence critical signaling pathways related to cellular proliferation and apoptosis. Recent research has underscored the significance of these compounds in the prevention and treatment of colorectal cancer by modulating signaling molecules such as BCL-2 and K-ras, thereby demonstrating anti-tumorigenic potential (Hossain et al., 2022; Kaefer & Milner, 2008). Furthermore, the antimicrobial properties of herbs and spices not only aid in food preservation by suppressing microbial proliferation but also bolster the immune system by diminishing the load of pathogenic microorganisms in the gastrointestinal tract (Khanal et al., 2021; Bukvički et al., 2020).

The nutritional composition of these ingredients is enhanced by the inclusion of trace elements and additional micronutrients. Investigations employing scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDX) have demonstrated that herbs and spices may harbor diverse trace minerals—including magnesium, aluminum, potassium, and molybdenum—that, despite their low concentrations, enhance both their nutritional significance and biochemical functionality (Hashim & Embong, 2022). Concurrently, research has emphasized supplementary nutritional components, including carotenoids and other antioxidants, which augment their advantageous attributes beyond simple flavor enhancement (Drewnowski, 2024).

The conventional application of herbs and spices in diverse medical systems has substantiated their potential as functional foods and nutraceuticals. Reviews of ethnobotanical data across various countries have systematically recorded the antimicrobial, antidiabetic, antihyperlipidemic, and hepatoprotective properties of indigenous herbs and spices (Khanal et al., 2021). This ancient knowledge is currently being corroborated by contemporary scientific research that emphasizes its role in regulating essential biochemical pathways associated with chronic diseases. The integration of herbs and spices into functional food products has emerged as a trend to enhance conventional foods with supplementary health benefits, thereby connecting traditional practices with contemporary nutritional science (El-Sayed & Youssef, 2019).

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Chapter 2

# Sustainable Foods and Consumption

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**Abstract**

Sustainable food is a concept defined to ensure the sustainability of food systems by bringing together environmental, social and economic dimensions. This concept aims to reduce the environmental impacts of food production and consumption, ensure food security and promote healthy nutrition. Sustainable food systems protect natural resources while also considering human health and social well-being. Sustainable food is often associated with diets that promote the consumption of plant-based foods. Developing sustainable food systems plays a critical role in societies achieving their food security and environmental sustainability goals. In this context, models such as community supported agriculture (CST) have significant potential for strengthening local food systems and ensuring environmental sustainability (Yıldırım, 2024). CST contributes to making food systems more sustainable by encouraging the participation of local communities in agricultural production processes.

## 1. Introduction

Sustainable food refers to food systems and dietary patterns that prioritize environmental health, social equity, and economic sustainability. The concept encompasses a variety of practices that aim to reduce the ecological footprint of food production and consumption while ensuring food security and nutrition for current and future generations. Sustainable diets are characterized by low environmental impacts, respect for biodiversity, and optimization of natural resources, as defined by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) (Gupta

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et al., 2022; , Klimczak and Gliszczyńska-Świgło, 2024). The sustainable food system aims to provide clean water, fertile soil and healthy food for future generations by protecting natural resources.

Food waste means that the food produced goes to waste without being consumed or processed. It is important to reduce this waste in terms of sustainability. Food waste can be minimized and a sustainable food cycle can be created with practices such as conscious consumption, correct storage methods and food sharing.

The increasing awareness of sustainability among consumers has led to significant changes in food purchasing behavior. Studies show that consumers increasingly prefer locally sourced, organic, and sustainably produced foods (Pinard et al., 2014). This trend is reflected in the practices of large food retailers and restaurants, such as large chains such as Wal-Mart and Costco, who have begun to adopt sustainable sourcing policies, such as switching to cage-free eggs (Pinard et al., 2014). Furthermore, the food industry plays an important role in promoting healthy and sustainable diets by integrating nutritional considerations into sustainability discussions, as highlighted by the EAT-Lancet Commission, which emphasizes the need for diets that are both nutritionally and environmentally sustainable (Miller et al., 2021).

Sustainable diets are not only about the types of foods consumed, but also the broader food systems that support these diets. For example, the Mediterranean diet is often cited as a model for sustainable nutrition because of its emphasis on plant-based foods, moderate consumption of animal products, and low environmental impact (Dernini & Berry, 2015). Additionally, sustainable food practices in the food service sector, such as waste reduction and energy efficiency, contribute to the overall sustainability of food systems (Ju & Chang, 2016).

Sustainable food encompasses a holistic approach to food systems that integrates environmental, social and economic dimensions. It requires collaboration between consumers, producers and policy makers to create an ecosystem that supports sustainable dietary practices while addressing the challenges of food security and environmental degradation.

## 1.1. Sustainable Food Consumption

Sustainable food consumption refers to the practice of choosing food products and dietary patterns that promote health and well-being while minimizing environmental impact. This concept encompasses several dimensions, including ecological sustainability, social responsibility, and economic viability. Increasing awareness of these dimensions has led to increased interest in how consumers can make choices that contribute to a more sustainable food system. A key aspect of sustainable food consumption is that it is compatible with environmental sustainability. This includes choosing food products that have a lower carbon footprint, are produced using environmentally friendly methods, and contribute to the preservation of biodiversity. In addition to environmental considerations, sustainable food consumption also encompasses social dimensions such as animal welfare and fair trade practices. Consumers are becoming increasingly aware of the ethical implications of their food choices, leading to increased demand for products that comply with humane animal treatment and equitable labor practices. This awareness is essential to promote a holistic approach to sustainability that considers not only the environmental impacts of food systems but also their social justice dimensions.

Sustainable food consumption can be achieved through a variety of practices, including plant-based foods, organic produce, locally sourced produce, fair trade produce, and seasonal produce. These choices not only support individual health, but also contribute to broader environmental and social sustainability goals. For instance, organic food is often highlighted as a sustainable choice due to its reduced reliance on synthetic pesticides and fertilizers, which can harm ecosystems Annunziata et al. (2019). However, the environmental benefits of organic food can vary, and there is ongoing debate about its overall sustainability compared to conventional farming practices (Rahman & Luomala, 2020).

Sustainable food consumption is influenced by socio-demographic factors, including age, education, and cultural background. Research indicates that younger consumers, particularly those from higher socio-economic backgrounds, are more likely to prioritize sustainability in their food choices (Wyrwa, 2023; Mota-Gutierrez, 2024). This demographic shift is crucial as it indicates a potential for increased demand for sustainable food products, which can drive changes in food production and supply chains (Biresselioglu, 2023).

In addition to environmental considerations, sustainable food consumption also encompasses social dimensions, such as animal welfare and fair trade practices. Consumers are increasingly aware of the ethical implications of their food choices, leading to a rise in demand for products that adhere to humane treatment of animals and equitable labor practices (Verain et al., 2012; Sánchez et al., 2021). This awareness is essential for fostering a holistic approach to sustainability that considers not just the environmental impact but also the social justice aspects of food systems.

Furthermore, the COVID-19 pandemic has underscored the importance of sustainable food consumption. The disruptions in food supply chains and the heightened awareness of food security issues have prompted consumers to reconsider their food purchasing behaviors. Many have shifted towards local and organic products, recognizing the benefits of supporting local economies and reducing food miles (Ramos et al., 2022). This shift is indicative of a broader trend towards sustainability, as consumers seek to make choices that are not only beneficial for their health but also for the planet.

To promote sustainable food consumption effectively, it is essential to implement educational programs that raise awareness about the environmental and social impacts of food choices. Policymakers and stakeholders in the food industry must work collaboratively to create frameworks that encourage sustainable practices, such as labeling initiatives that inform consumers about the sustainability of food products (Jones et al., 2011; Matschoss, 2022).

### 1.2. Sustainable Food Examples

Sustainable food consumption encompasses a variety of food choices that prioritize environmental health, social equity, and economic viability. Examples of sustainable foods include plant-based foods, organic products, locally sourced items, fair trade goods, and seasonal produce all of which contribute to reducing the ecological footprint of our diets.

*Plant-Based Foods*: A significant shift towards plant-based diets is one of the most effective strategies for promoting sustainable food consumption. Research indicates that diets rich in legumes, nuts, whole grains, and vegetables can substantially lower greenhouse gas emissions (GHGE) compared to meat-heavy diets Brink et al. (2019). For instance, replacing meat with legumes and nuts not only reduces environmental impact but also supports health by providing essential nutrients (White & Hall, 2017). The Mediterranean diet, which emphasizes plant-based foods, is often cited as a sustainable dietary model due to its health benefits and lower environmental impact (Donini et al., 2016).

*Organic Foods*: Organic products are another example of sustainable food choices. These foods are produced without synthetic pesticides and fertilizers, which can harm ecosystems. The demand for organic foods has been increasing as consumers become more aware of their health benefits and environmental sustainability (Verain et al., 2015). Studies show that organic farming practices can enhance biodiversity and soil health, making them a preferable choice for environmentally conscious consumers (Huang et al., 2022). However, the sustainability of organic foods can vary, and it is essential to consider the entire food system when evaluating their environmental impact (Rahman & Luomala, 2020).

*Locally Sourced Foods*: Foods that are sourced locally contribute to sustainability by reducing transportation emissions and supporting local economies. Local food systems often prioritize seasonal produce, which can lead to fresher and more nutritious options for consumers (Braun et al., 2018). Initiatives such as farm-to-school programs exemplify how local sourcing can enhance the sustainability of food procurement in educational settings, promoting both environmental and social benefits (Pagliarino et al., 2021). Additionally, local foods often have a smaller carbon footprint compared to imported goods, making them a more sustainable choice (Utzig, 2019).

*Fair Trade Products*: Fair trade foods, which ensure that producers receive fair compensation and work under safe conditions, are also integral to sustainable consumption. These products often include coffee, chocolate, and certain fruits. By choosing fair trade options, consumers can support ethical practices in food production and contribute to social sustainability (Verain et al., 2012). This approach aligns with the principles of sustainable food consumption by addressing social equity alongside environmental concerns.

*Seasonal Foods*: Consuming seasonal foods is another effective way to practice sustainable food consumption. Seasonal foods are typically fresher, require less energy for storage and transportation, and are often more affordable. This practice encourages consumers to adapt their diets based on what is locally available at different times of the year, which can help reduce reliance on out-of-season produce that often has a higher environmental impact due to long-distance transportation (Harray et al., 2018).

### 1.3. Countries best practicing sustainable food consumption

Countries that exemplify best practices in sustainable food consumption often integrate environmental, social, and economic considerations into their food systems. These nations typically promote policies that encourage organic farming, local sourcing, and reduced food waste while fostering consumer awareness about sustainability. Below are several countries recognized for their efforts in sustainable food consumption:

*Sweden*: Sweden is often cited as a leader in sustainable food practices. The country has implemented a comprehensive food policy that emphasizes sustainability across all levels of food production and consumption. The Swedish government promotes organic farming and has set ambitious targets to reduce greenhouse gas emissions from the food sector. Research indicates that Swedish consumers are increasingly prioritizing environmental and ethical considerations in their food choices, which aligns with national sustainability goals (Rejman et al., 2019). Additionally, Sweden's focus on plant-based diets and reducing meat consumption has been pivotal in its sustainability efforts (Diachkova et al., 2022).

*Denmark*: Denmark is recognized for its strong emphasis on organic food production and consumption. The Danish government has established policies that support organic farming, aiming for 60% of all food consumed in public institutions to be organic by 2025. Danish consumers are also increasingly adopting flexitarian and plant-based diets, further contributing to sustainability (Mota-Gutierrez, 2024). The country's commitment to reducing food waste through initiatives like the "Stop Wasting Food" movement has also garnered international attention (Annunziata et al., 2019).

*Germany*: Germany has made significant strides in promoting sustainable food consumption through its "National Strategy for Sustainable Development," which includes initiatives to enhance organic farming and reduce food waste. German consumers show a high level of awareness regarding sustainability, often choosing organic and locally sourced products (Rejman et al., 2019). Moreover, Germany's robust food labeling system helps consumers make informed choices about the sustainability of their food (Pércsi, 2024).

*Italy*: Italy is known for its rich culinary traditions that emphasize local and seasonal foods. The Italian government supports sustainable agriculture through various programs aimed at preserving biodiversity and promoting organic farming. The country has also embraced the Mediterranean diet, which is recognized for its health benefits and lower environmental impact (Ferrari et al., 2020). Italian consumers are increasingly aware of the importance of sustainability, leading to a rise in the consumption of organic and locally produced foods (Annunziata et al., 2019).

*Netherlands*: The Netherlands is a pioneer in sustainable agriculture, particularly in the realm of innovative farming techniques that reduce environmental impact. The Dutch government has implemented policies to promote sustainable food systems, including initiatives to enhance food security and reduce food waste (Diachkova et al., 2022). Dutch consumers are increasingly interested in sustainability, often opting for organic products and supporting local food systems (Rejman et al., 2019).

*France*: France has a long-standing tradition of valuing high-quality food, which has translated into a growing interest in sustainable consumption. The French government has introduced policies to promote organic farming and reduce food waste, including the "Anti-Waste Law" that mandates supermarkets to donate unsold food (Mourad, 2016). Additionally, French consumers are increasingly adopting plant-based diets, contributing to the overall sustainability of the food system (Mota-Gutierrez, 2024).

### 1.4. Turkey's position in sustainable food consumption

Turkey's position in sustainable food consumption is multifaceted, with challenges and opportunities, particularly in agriculture and food systems. The country has recently taken steps to improve food security and sustainability.

*Food Security and Agricultural Policies*: Turkey has recognized the importance of food security and has implemented various policies aimed at improving agricultural productivity and sustainability. The government has focused on enhancing food security through initiatives that support local farmers and promote sustainable agricultural practices. However, bureaucratic challenges and rigid regulations often hinder effective implementation, leading to inefficiencies in the food system (Ekici, 2023).

*Economic Factors and Food Prices*: Economic conditions, particularly inflation, significantly impact food consumption patterns in Turkey. Rising food prices, driven by supply shocks and currency fluctuations, have restricted consumers' ability to purchase sustainable food products. This economic pressure can lead to a reliance on cheaper, less sustainable food options, which poses a challenge to promoting sustainable consumption practices among the population (Akın et al., 2019).

*Consumer Awareness and Behavior*: There is a growing awareness among Turkish consumers regarding the importance of sustainability in food choices. However, the prevalence of unhealthy food advertising, which often promotes high-fat, high-sugar products, complicates efforts to shift consumer behavior towards healthier and more sustainable options (Güran et al., 2010). The challenge lies in effectively educating consumers about the benefits of sustainable food consumption and providing them with accessible alternatives.

*Environmental Policies and Agricultural Practices*: Turkey's environmental policies have begun to address the sustainability of its agricultural practices. The country has made commitments to improve its environmental performance, but the effectiveness of these policies is often undermined by economic growth strategies that prioritize short-term gains over long-term sustainability (Acar & Gultekin-Karakas, 2016). For example, the reliance on fossil fuel subsidies has been criticized for detracting from investments in cleaner agricultural technologies (Acar et al., 2018).

*Integration of Sustainable Practices*: Despite these challenges, there are positive developments in Turkey's approach to sustainable food consumption. Initiatives aimed at promoting organic farming and local food systems are gaining traction. The Turkish government has also been encouraged to adopt more integrated approaches to food policy that consider environmental, social, and economic dimensions (Çelik & Serin, 2022).

## 1.5. Sustainable food consumption behaviour gap

The gap between sustainable food consumption attitudes and actual behaviors is often referred to as the "attitude-behavior intention" disconnect. This disconnect suggests that while individuals may express positive attitudes towards sustainable food practices, these attitudes do not consistently translate into corresponding purchasing behaviors. The gap between sustainable food consumption attitudes and actual behaviors is influenced by a complex interplay of knowledge, values, social influences, and educational factors. While positive attitudes towards sustainability exist, translating these into consistent behaviors remains a challenge. Addressing this gap requires multifaceted approaches that consider the unique motivations and barriers faced by different consumer segments. Shanks et al. found that participants' knowledge about sustainable food systems did not lead to significant changes in their dietary practices over time, indicating a persistent gap between intention and action (Shanks et al., 2012). Similarly, a survey of dietitians revealed that only 47% incorporated sustainable food principles into their practices, highlighting a lack of self-efficacy and inconsistent training regarding sustainability in dietetics education (Hawkins et al., 2019).

Several studies have explored the determinants of sustainable eating behaviors, particularly among specific demographics such as university students. Mollaei et al. conducted focus group discussions that revealed key perceptions and determinants influencing sustainable eating behaviors among Canadian university students, emphasizing the importance of targeted interventions to promote sustainable habits (Mollaei et al., 2023).

Additionally, Larson et al. demonstrated that young adults who value sustainable practices tend to consume diets of higher nutritional quality, suggesting that fostering these values could bridge the gap between attitudes and behaviors (Larson et al., 2019). However, despite these positive correlations, many consumers still struggle to align their food choices with their sustainability values, as evidenced by Rejman et al., who noted a significant gap between consumers' favorable attitudes towards sustainability and their actual food purchasing behaviors (Rejman et al., 2019).

Education and awareness play crucial roles in shaping sustainable food consumption behaviors. Arslan and Alataş found that increasing education levels did not necessarily correlate with improved sustainable eating habits, indicating that knowledge alone may not be sufficient to drive behavioral change (Arslan & ALATAŞ, 2023). Furthermore, Kamenidou et al. identified that Generation Z university students primarily focused on seasonal and regional food consumption, suggesting that specific behavioral segments exist within this demographic that could be targeted for interventions (Kamenidou et al., 2019). The literature also indicates that personal values and social influences significantly impact sustainable food choices, as noted by Olsen and Tuu, who found that environmental values mediate the relationship between future time perspective and sustainable consumption behaviors (Olsen & Tuu, 2021).

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Chapter 3

# Ohmic Cooking in Food Technology

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**Abstract**

Cooking is an important process for food technology. Many foods must undergo a cooking process before they are consumed. Recently, it has been observed that especially cooked products have become more common in markets. At this point, the method used in the cooking process become more of an issue. Traditional heating techniques in the food industry utilize conduction, convection, or radiation to transfer heat from an environment like water, air, or oil to the food. However, due to the product size and shape, it can take a significant amount of time for heat to reach the center and achieve a safe internal temperature. This often results in uneven cooking, with some areas being overdone while others remain undercooked, ultimately compromising the product's quality (Kumar et al., 2014). As a result, alternative technologies are needed to address these challenges. Ohmic cooking is a promising emerging method for food processing that offers a potential substitute for traditional heat treatments. This technique produces heat internally by applying an alternating electric current directly to the food, the food electrical resistance produces thermal energy through joule heating. Essentially, in ohmic cooking, the food itself becomes a component of the electrical circuit (Jafarpour et al., 2022). Therefore, ohmic heating and cooking are of interest for food processing and industrial applications (Liu et al., 2007).This study presents the findings of investigations on ohmic cooking, the principle of ohmic cooking, the basic components of ohmic cooking, the advantages of ohmic cooking, the limitations of ohmic cooking, and the comparison of ohmic cooking with conventional cooking and the combination of ohmic cooking with other cooking methods.

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## 1. Introduction

Ohmic cooking, or Joule heating, works by applying an alternating electric current directly to the food, which generates heat interiorly. This technique provides quick and even heating, resulting in greater energy efficiency and enhanced food quality. Ohmic heating enables swift temperature increase in materials, usually occurring within seconds to a few minutes (Farahnaky et. al., 2018).

Ohmic cooking is commonly categorized as one of the 'innovative food processing technologies.' The key innovation of ohmic heating rests in its capacity to generate heat internally within the food, distinguishing it from other conventional heat processing methods that rely on heat transfer through conduction or convection, as seen in most heat exchange systems. The rate at which heat is generated per second (heating rate) is influenced by both the voltage gradient and the electrical conductivity of the material. The primary factor affecting the ohmic heating rate is the electrical conductivity of the material, which is influenced by various factors, including temperature, ionic strength, the microstructure of the material, the presence and concentration of a second phase, and the concentration of non-electrolytes, among others (Vicente et al., 2006).

Ohmic heating has been shown to efficiently process a variety of liquid and liquid-solid food products in a relatively short time. Research has demonstrated its effectiveness in pasteurizing juices. The efficiency of this method is influenced by external factors such as electric field strength and frequency, as well as internal factors like pH and sugar content. One of the key advantages of ohmic heating is the consistent temperature distribution within the product, which prevents surface overheating and helps maintain the food's sensory qualities. Compared to conventional thermal methods used in commercial settings, ohmic heating requires less energy and significantly reduces heating time. Some studies have found that the shelf life of foods treated with ohmic heating is equal to or even longer than that of those processed with traditional heat methods. Additionally, a wide range of research supports the conclusion that ohmic heating is highly effective in various food manufacturing processes, with minimum impact on the nutritional, functional, and sensory attributes of food, while enhancing product quality and contributing to enzyme inactivation (Alkanan et al., 2021).

### 1.1. The Principles of Ohming Heating

Ohmic heating derives its name from Ohm's Law which forms the basis of the process. The fundamental principle involves applying Ohm's Law, represented by the equation:

$R = V/I$

R (ohm) is the resistance between two points in a circuit, V is the voltage (volt) and I is the current (ampere) (Kumar et al., 2014; Aurina & Sari, 2021).

As stated by Ohm's Law, the electric current flowing through a conductor increases with the applied voltage and decreases with higher resistance. To generate electrical current, a power source or generator is essential. The electric current flows through the matrix via electrodes that contact the food. The electrode gap can be adjusted to achieve the desired electric field strength. Electricity from the generator travels to the first electrode, passing through the food placed in the electrode gap. The food's resistance to current flow causes internal heating. The current then moves to the second electrode and returns to the power source, completing the circuit. The insulator cap around the electrodes regulates the environment inside the device. The two primary factors affecting heat generation are the electric field strength and the residence time (Kour et al., 2023).

### 1.2. The Role of Electrodes in Ohmic Heating

In ohmic heating, electrode surfaces function as an interface between a solid-state conductor and a liquid or semi-solid conductive medium. These interfaces play a vital role in ensuring efficient current transfer into the heating environment. From an electrochemical perspective, it is well established that both the physical structure and chemical composition of electrode surfaces significantly affect the interfacial phenomena occurring at the electrode–electrolyte boundary. With certain electrode materials, specific electrochemical reactions may exhibit sluggish kinetics or may not proceed at all, while with different electrodes, the same reaction may happen more rapidly under identical conditions. Therefore, understanding the behavior of electrodes in ohmic heating is essential to prevent or control electrochemical reactions by selecting suitable electrode materials (Liu et al., 2007).

### 1.3. Key Components of Ohmic Cooking Systems

Ohmic cooking operates through the integration of several essential components that collectively enable efficient, uniform, and precisely controlled heating. These elements are fundamental to achieving optimal outcomes in terms of both product quality and energy performance. The power source, electrodes, and the electrode spacing collaborate to generate the electric field required for consistent internal heating of the food matrix. Meanwhile, components such as the insulator cap and cooling system play a crucial role in maintaining operational safety and system stability. Accurate and responsive temperature regulation ensures that cooking is consistent and preserves the desired sensory and nutritional characteristics of the food. By carefully selecting electrode materials and optimizing system parameters, ohmic heating setups can be customized for a broad spectrum of food types, enhancing both processing efficiency and final product quality. The following provides an overview of the core components of an ohmic cooking system and highlights their significance in the overall process.

### 1.3.1 Power Supply

The power supply serves as a fundamental component of an ohmic cooking system, responsible for delivering the electrical current that flows directly through the food to generate internal heat. It must be capable of precisely regulating both voltage and current in accordance with the specific electrical and thermal properties of the food being processed. This regulation is essential to ensure safe and efficient system operation, maintaining a stable and consistent energy input throughout the cooking cycle. By controlling the intensiveness of the electric field applied across the food matrix, the power supply directly affects the heating rate and consistency, thereby playing a critical role in achieving the desired thermal performance and product quality (Suh et al., 2006).

### 1.3.2. Electrodes

Electrodes function as the primary conductive elements in an ohmic cooking system, responsible for delivering electrical current directly into the food matrix. They are commonly constructed from high-conductivity, corrosion-resistant materials such as stainless steel or graphite to withstand extended operational conditions without degradation. Positioned in direct contact with the food, the electrodes facilitate the flow of current through the product, inducing volumetric heating. The overall efficiency and performance of ohmic heating are significantly impacted by the selection and configuration of electrode materials. Appropriate material choice ensures stable electrical conductivity, minimizes the risk of electrochemical reactions, and supports consistent thermal transfer. Additionally, factors such as electrode surface area and spatial arrangement play a crucial role in promoting uniform current distribution and achieving homogeneous heating throughout the product (Liu et al., 2007).

### 1.3.3. Food Product (Heating Medium)

In ohmic cooking, the food itself serves as the medium for heat generation, with its electrical resistivity playing a key role in determining how effectively electrical energy is converted into heat. Foods with higher resistivity produce more heat when exposed to the same electrical current, resulting in faster and more efficient heating. One of the main advantages of ohmic cooking is its ability to heat food uniformly throughout, from the inside out, thereby reducing the risk of overcooking or uneven heat distribution, which is often encountered with traditional heating methods (Kour et al., 2023).

### 1.3.4. Electrode Gap

The electrode gap, which is the distance between the electrodes, is a critical parameter influencing the efficiency of the ohmic heating process. This gap directly affects the intensity of the electric field within the food product. A smaller gap generally results in a stronger electric field, leading to faster heating, while a larger gap weakens the field and slows down the heating rate. By adjusting the electrode gap according to the specific characteristics of the food being processed, uniform heat distribution can be achieved. Optimizing the gap size is essential for enhancing energy efficiency, reducing cooking time, and ensuring consistent product quality throughout the process (Jayasinghe et al., 2009).

### 1.3.5. Insulator Cap

The insulator cap encases the electrodes and is essential for ensuring both safety and operational efficiency in the ohmic cooking system. It serves to prevent accidental electrical contact and shields the system from potential short circuits. By directing the electrical current exclusively through the food product, the insulator cap protects other components from damage. Additionally, it helps control the environmental conditions within the cooking chamber, preserving both the food's quality and the integrity of the electrodes during the process. Effective insulation is crucial for maintaining food safety while enhancing the durability and longevity of the system (Suh et al., 2006).

### 1.3.6. Temperature Control System

Precise temperature regulation is vital in ohmic cooking to prevent both overheating and underheating of the food. The temperature control system consists of sensors that continuously monitor the temperature of the food and electrodes. These sensors send real-time data to a control unit, which adjusts the power supply to maintain the target temperature. Consistent temperature control is essential for preserving the food's texture, flavor, and nutritional value, while also preventing damage caused by overexposure to heat (Kour et al., 2023). This system ensures that the food is cooked uniformly and accurately, maintaining high-quality standards.

### 1.3.7. Cooling System

A cooling system is utilized to remove excess heat from the system, ensuring that optimal operating temperatures are maintained. It is crucial for preventing the overheating of the electrodes, power supply, and other critical components of the cooking system. Without proper cooling, heat accumulation could decrease system efficiency and shorten the lifespan of its components. The cooling system may incorporate air or water-based methods to effectively regulate the temperature and maintain the system's performance (Jayasinghe et al., 2009).

### 1.3.8. Electrode Material

The choice of material for the electrodes is critical to the system's performance. Materials such as stainless steel and graphite are commonly selected for their excellent electrical conductivity and resistance to corrosion. These electrode materials are durable, capable of withstanding prolonged exposure to both food products and electrical currents without deterioration. The material selection impacts both the efficiency of the heating process and the overall longevity of the system (Liu et al., 2007). Materials that are resistant to corrosion ensure the long-term effectiveness of the electrodes, reducing the need for frequent maintenance or replacement.

## 1.4. Comparing Ohmic Cooking with Conventional Methods

Studies comparing ohmic and conventional cooking have been reviewed and some of them are presented below.

Piette et al. conducted a study to assess the feasibility of ohmic heating as an alternative thermal processing technique for the cooking of processed meat products, specifically examining its effects on selected physicochemical and sensory quality parameters relative to those produced using conventional smokehouse methods. The study found that variations in electrical heating rate, core temperature endpoints, and a standardized 20-minute isothermal holding phase exerted negligible influence on the overall quality attributes of ohmic-cooked sausages. Notably, the ohmically processed sausages demonstrated comparable characteristics to their traditionally smoked counterparts across most measured parameters, with the exception of texture, which was consistently softer ($P > 0.05$) in ohmic samples (Piette et al., 2004).

De Halleux et al. investigated the applicability of a resistive (ohmic) heating cell for the thermal processing of Bologna ham, with a focus on evaluating its energy efficiency and pasteurization performance. Utilizing a prototype ohmic cooking cell, the study demonstrated the feasibility of conducting accelerated batch cooking operations. In comparison to conventional smokehouse techniques, the ohmic process achieved a substantial reduction in processing time—by approximately 90–95%—alongside significant energy savings ranging from 82% to 97% (De Halleux et al., 2005).

Bozkurt and İçier assessed the feasibility of ohmic heating as an alternative thermal processing method for meat products by comparing its effects on quality parameters with those of conventional cooking. In their study, beef samples containing different fat levels were exposed to ohmic heating under electric field strengths of 20, 30, and 40 V/cm, as well as to traditional cooking techniques. The findings indicated that ohmic heating offers a rapid and efficient alternative for thermal processing of meat products, with potential advantages in processing time and quality retention (Bozkurt & İçier, 2010).

Farahnaky et al. evaluated the impacts of ohmic heating on the stability of key bioactive constituents; ascorbic acid, flavonoids, and phenolic compounds, in selected vegetables including turnip, kohlrabi, radish, and potato, by comparing conventional and microwave processing methods. The findings indicated that conventional heating, due to its extended processing durations and higher thermal load, led to significant degradation of nutritionally valuable phytochemicals. Ohmic heating was found to enhance the rate of texture softening while promoting superior retention of vitamin C and other bioactive compounds, thereby demonstrating its potential as a more efficient and nutritionally favorable alternative to conventional thermal treatment systems (Farahnaky et al., 2018).

Gavahian et al. investigated the effectiveness of ohmic and microwave heating techniques for Middle Eastern-style rice preparation, comparing them with conventional hotplate-based cooking, with particular emphasis on the alterations in physical and textural attributes of rice grains during thermal processing. The study found that microwave heating did not significantly reduce cooking time, whereas ohmic heating effectively mitigated several limitations associated with traditional methods, including extended processing duration, elevated energy consumption, and surface fouling. Ohmic heating demonstrated superior energy efficiency and reduced the thermal come-up time by approximately 48% compared to conventional cooking. Additionally, kinetic analysis of texture modification revealed that ohmic heating facilitated a higher softening rate of rice grains relative to other evaluated methods (Gavahian et al., 2019).

Tumpanuvatr and Jittanit compared the quality characteristics of brown rice cooked using ohmic and conventional methods, along with their respective energy consumption. The study found that ohmic heating significantly reduced the degree of retrogradation in the cooked rice samples compared to conventional cooking. However, the ohmic cooking system exhibited higher electrical energy usage, requiring approximately 1.7 to 2.6 times more energy than the conventional method under similar processing conditions (Tumpanuvatr & Jittanit, 2022).

Astráin-Redín et al. explored the application of specific power input and cooking value to evaluate product-process interactions and to compare performance with conventional cooking methods. The study aimed to evaluate the impact of varying specific power remarks on the texture and cellular injury of carrots, and to compare an optimised ohmic cooking process in comparison with conventional boiling based on physical properties and energy efficiency. The results indicated that ohmic cooking achieved greater softening and more extensive cell breakdown in carrot tissue compared to conventional boiling. Furthermore, the use of ohmic heating notably decreased both cooking duration and energy consumption (Astráin-Redín et al., 2024).

## 1.5. Combining Ohmic Cooking with Other Methods

There are some studies in the literature where ohmic and other cooking methods are carried out together. These are presented below.

Özkan et al. investigated the combined use of ohmic and plate heating for cooking hamburger patties, finding it highly effective in reducing cooking time and enhancing product safety. They summarized their experimental study on the hamburger patties quality cooked using both conventional and ohmic-assisted methods, evaluating various properties such as mechanical strength, oil content, and moisture levels. The findings indicated that no notable differences were observed in the characteristics of patties prepared using either cooking method (Özkan et al., 2004).

Choi et al. proposed the combination of ohmic and microwave heating to enhance the consistency of heat treatment in foods containing solid particulates. In their research, they developed and successfully validated simulated heating patterns for both solid and liquid phases under ohmic and microwave combination heating, accounting for dynamic fluid flow. They suggested that their findings could aid in the design of a continuous flow system combining ohmic and microwave heating technologies, which would minimise the risk of overprocessing or underprocessing during heat treatment (Choi et al., 2011).

Sengun et al. investigated the impact of a combined ohmic–infrared cooking system on the meatballs microbiological quality, where the meatballs underwent infrared cooking following an ohmic precooking treatment. The treated meatballs were analyzed for the presence of total mesophilic aerobic bacteria, molds and yeasts, *Clostridium perfringens*, *Staphylococcus aureus*, *Listeria monocytogenes, Salmonella spp*., and *Escherichia coli* O157:H7. The study concluded that this two-step cooking process effectively enhanced the microbiological safety of the meatballs (Sengun et al., 2015).

Uzun Özcan et al. examined the effect of ohmic cooking alone and its sequential application with infrared cooking on lipid oxidation and the formation of polycyclic aromatic hydrocarbons (PAHs) in beef. The study found that both lipid oxidation and PAH concentrations increased at higher ohmic voltages and elevated infrared temperatures. Optimal conditions, such as using 40 and 55 volts for ohmic cooking alone, and combinations like 40 V–325 °F or 40 V–375 °F for ohmic-infrared cooking, were identified to maintain TBARS values below the acceptable threshold ($<1$ mg/kg MDA). Additionally, PAH levels across all treatment groups remained below the legal limits set by the European Commission, indicating that the ohmic cooking process followed by infrared treatment is safe in terms of PAH content (Uzun Özcan et al., 2018).

Joe et al. created ohmic and vacuum integration heating system designed to process senior-friendly food products consisting of both solid components and liquid. By integrating vacuum and agitation with ohmic heating in multiphase food, they effectively reduced the base solution boiling point, improved the model food thermal consistency, and facilitated the softening of solid particles. This approach also helped prevent excessive heat treatment within the multiphase food. Moreover, this heating system with agitation shows significant promise for processing senior-friendly foods, enhancing the texture of solid-phase ingredients, and improving thermal consistency (Joe et al., 2021).

Turgut et al. studied the combined application of ohmic heating and convective drying as an innovative approach to drying. Processing conditions, as the velocity of air, temperature of drying and applied voltage were examined to minimize the drying time of potato slices and to assess their impact on certain quality attributes of the final product. Ohmic assisted drying system effectively reduced both time and cost by eliminating the blanching stage in the drying process, owing to the substantial enzyme inactivation achieved (Turgut et al., 2022).

## 1.6. Advantages of Ohmic Cooking

The ohmic system has gained significant attention from researchers due to its high electrothermal efficiency, straightforward design, ease of equipment control, and consistent, rapid heating. Furthermore, its lack of waste byproducts and extremely low operational costs offer notable advantages (Ding et al., 2021).

In an ohmic heating system, the food experiences rapid and uniform heating (1°C/s) throughout, ensuring consistent temperature distribution in both solids and liquids when their resistances are similar. Additionally, heat transfer coefficients do not constrain the heating rate and temperatures suitable for Ultra High Temperature (UHT) processing can be efficiently attained in this system. In ohmic cooking, unlike conventional heating, heat transfer occurs without the presence of hot surfaces, eliminating the danger of surface fouling or burning, which reduces the need for frequent cleaning. Moreover, compared to microwave heating, the capital costs of the ohmic cooking process are lower. Ohmic cooking ensures that thermally sensitive foods or components are protected from localized thermal degradation due to the consistent distribution of heat and it boasts high energy conversion efficiencies (>90%). Furthermore, the ohmic process is well-suited for continuous processing (Sastry, 1994; Rahman, 1999).

Ohmic cooking enables exact temperature regulation, that is critical for maintaining both food safety and the quality of the final product. In certain applications, it can lead to lower nutrient degradation compared to conventional thermal treatments like extended boiling, owing to its rapid and uniform heat distribution. This efficiency allows for lower processing temperatures and shorter thermal exposure times. Furthermore, because heat is generated internally via electrical current, there is no reliance on external heating media such as water, thereby minimizing nutrient losses due to leaching. The swift microbial inactivation achieved through ohmic processing may also reduce the necessity for chemical preservatives.

Moreover, the limited thermal exposure helps preserve the structural and sensory integrity of the food, reducing the need for additional additives to restore quality attributes typically compromised by traditional heat processing (Dos Santos et al., 2024).

### 1.7. Limitations for Ohmic Cooking Process

Ohmic heating, despite its benefits like quick and uniform heating, has several drawbacks that can limit its use in food processing:

**High Initial Equipment Costs**: Establishing ohmic heating systems requires significant initial investment, which can be a barrier for small-scale operations. The initial investment in ohmic heating systems is higher compared to conventional methods (Alkanan et al., 2021).

**Limited Applicability to Low Conductivity Foods**: Foods with high fat content, especially those containing fat granules, do not heat efficiently with ohmic heating due to their low electrical conductivity, as they lack sufficient water and salts. This can lead to uneven heat treatment, where pathogenic bacteria within the fat granules are less exposed to the heat compared to bacteria outside the fat particles. Furthermore, as temperature increases within the system, so does the electrical conductivity of both the food and the solution due to enhanced electron movement (Alkanan et al., 2021).

**Electrode Corrosion and Electrochemical Reactions:** Another challenge is the electrode corrosion caused by the reactions of electrochemical, which not only influences the system efficiency and the food quality but also increases maintenance costs as the process continues (Alkanan et al., 2021; Jafarpour D. et al., 2022).

**Potential quality issues:** Certain studies have indicated that ohmic heating may negatively impact specific physical attributes of food products, including color stability (Jafarpour D. et al., 2022). Depending on the composition of the food matrix and the applied processing parameters, ohmic heating may adversely impact sensory attributes such as texture, color, and flavor. Additionally, a potential drawback is the migration of metallic ions from the electrodes into the food product, which could pose safety or quality concerns (Dos Santos et al., 2024).

**Frequency Limitations:** Some researchers have pointed out that one such disadvantage is its narrow frequency range (Alkanan et al., 2021).

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Chapter 4

# Food Safety, Food Adulteration and Fraud

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**Abstract**

Food health and food safety are vital for ensuring both health and economic sustainability in the food sector. Implementing food safety standards and raising consumer awareness underpin policies and strategies in these areas. Food safety is the totality of systems established to ensure that food products reach the consumer in a safe, healthy and high quality manner. Food security is an important concept that defines people's access to sufficient, safe and nutritious food. Food health covers all practices to ensure that food is consumed without adverse health effects. Food security is critical for meeting basic food needs, ensuring food security and adequate nutrition. Systems that function throughout the process from food production to consumption are vital for the existence of a healthy society. Food security and health are critical for individuals to lead a healthy life. Not only physiological needs need to be met, but also psychological and social needs need to be taken into account. Therefore, not only food production, but also the healthy processing, storage and distribution of this food is essential. Food security ensures the growth of healthy individuals and the protection of public health, while healthy food is the basis of this security.

## Introduction

Food health and food assurance refers to the totality of the systems that a business establishes to ensure the safety, health and quality of food products. While food health includes the measures to be taken to ensure that the foods offered to consumers are not harmful to health and are of good quality, food assurance guarantees the reliability and conformity of these products

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to expectations (Eren et al., 2017, Akın & Akın, 2020). Food health aims to minimize health risks that may arise from the consumption of food. In this context, it is of great importance to comply with hygiene standards throughout the food production process. Food processors' compliance with hygiene rules such as hand hygiene and mask use is essential to protect the health of both employees and consumers (Dalyan et al., 2023). Food safety, on the other hand, has a broader meaning; it covers standardization and inspection in the production, processing, storage and distribution stages of food. Food safety has a critical role in increasing consumer confidence in food sources (Eren et al., 2017). Food safety is often supported by various standards and certifications. These standards ensure that products are safe for health, prepared with proper processing methods and meet consumer expectations. Some international standards used to ensure the safety of food products include Hazard Analysis Critical Control Point (HACCP), ISO 22000 and British Retail Consortium (BRC). These standards, combined with food safety management systems, contribute to the provision of quality and reliable products (Delesa, 2017; Ren et al., 2016). Furthermore, consumer information and traceability of products are important components of food safety. Food products that consumers trust are often supported by elements such as labeling, certification and transparency. This process reduces consumers' concerns about food safety and quality, giving them confidence in products (Benni et al., 2019; Wu et al., 2021). To meet consumer demands, cooperation between food producers and retailers has become important, which increases the effectiveness of food assurance (Marucheck et al., 2011). The success of the food safety system also depends on the compliance of producers and retailers with legal regulations on food safety and quality. To this end, governments and inspection bodies ensure that the implementation of food safety standards is monitored and audited. Thus, both consumer safety is enhanced and the overall quality of food products is improved (Kotsanopoulos a& Arvanitoyannis, 2017)

## 1.1 Food Safety in the World

Food safety in the world is an important issue that directly affects people's health and quality of life. Food safety plays a critical role in ensuring healthy and safe food at every stage of food production. In this context, food safety is a complex issue in both developed and developing countries (Nagyová et al., 2019). Food safety is particularly critical for preventing health problems such as foodborne diseases and contamination. The World Health Organization (WHO) has developed various strategies to mitigate food crises by making food safety a public health priority (Shrivastava et al., 2015). Food safety involves not only healthy food production but also supply chain management. Therefore, it is important to increase the quality control of agricultural practices and food processing stages to ensure the traceability and safety of food products (Vallée & Charlebois, 2015). There are some strategic approaches that should be followed to improve food security worldwide. These include adopting good agricultural practices (GAPs), establishing food traceability systems and developing the necessary inspection mechanisms for healthy food production (Li et al., 2023). In addition, raising public awareness and expanding education are considered among the most important elements of food safety (Ayyad et al., 2022). The COVID-19 pandemic has also revealed its impacts on food systems. Disruptions in food supply chains during the pandemic have created serious risks that threaten food safety. Accordingly, it has become inevitable to develop safe and sustainable food systems to cope with the challenges posed by the pandemic (Cable et al., 2020). In short, food security across the globe remains an area that needs to continuously evolve to ensure both the health of individuals and the sustainability of societies. Food safety is a global challenge and international cooperation, legal regulations and public awareness should be increased to overcome this problem. Countries should use scientific and social knowledge to strengthen their food safety strategies and take effective measures to minimize risks. Ongoing challenges to food safety include food bans, adulteration and market imbalances. It is inevitable to establish an effective inspection mechanism to ensure food safety at every stage, from production to distribution. In addition, increasing public awareness will strengthen consumers' demand for safe food and reinforce the trust relationship between producers and consumers (Niyaz & Inan, 2016).

### 1.1 Food Fraud

Food fraud is defined as the deliberate alteration of the quality and safety of food products and includes various fraudulent activities carried out for economic gain. Types of food fraud include misrepresentation of additives, violations of hygiene standards, and false food labeling Spink et al. (2019). Food fraud both increases risks to consumers' health and has a negative impact on overall food safety. The harms of food fraud are multifaceted. First, it can create health problems. Counterfeit foodstuffs or products containing debilitating substances can jeopardize the health of consumers. Especially nutritionally vulnerable groups (children, the elderly, the chronically ill) are more vulnerable to such fraud (Soon et al., 2023). Fraudulent foods can cause foodborne illnesses, allergic reactions or long-term health problems. Second, food fraud can lead to economic losses. The food industry can suffer serious economic losses due to the distrust created by fraudulent products. When consumers' trust is shaken, brands and producers can suffer from loss of revenue and reputational damage (Dasenaki & Thomaidis, 2019). In particular, major food scandals have resulted in significant declines in sales, which can lead to market instability in the long run (Agnoli et al., 2016). The consequence of food fraud is the need to tighten food safety regulations and inspections. Although these regulations are intended to raise food safety standards, the implementation of strict inspections can be economically burdensome for businesses (Creydt & Fischer, 2018). Food safety gaps also strain government resources in this area. Food fraud can create a general climate of mistrust in society, which creates obstacles to the provision of a satisfactory food system. Consumers who are concerned about the quality and safety of their food purchases are therefore more likely to seek out trustworthy products (Chang et al., 2022). It is important to ensure a healthy flow of information on food safety and to increase trust between consumers and producers. The harms of food fraud have serious consequences for both individual health and the economy. Therefore, effective inspection mechanisms, training programs and consumer information studies are inevitable to ensure food safety.

## 1.2 Food Adulteration

Food adulteration refers to the deliberate alteration of the content of a particular food product, exceeding quality and safety standards, or the addition of misleading substances in order to obtain additional costs or other advantages. Food adulteration is an important problem that threatens consumer health and jeopardizes food safety. In this article, the causes, types and effects of adulteration in foods and the measures to be taken in this area will be discussed.

Causes of Adulteration

The most common reason for food adulteration is economic considerations. It is common practice for manufacturers to use low-quality ingredients or dilute products to reduce costs and increase profits. Adulteration can often occur at any stage of the supply chain of foodstuffs, which can be caused by a lack of strict inspection and certification (Spink et al. (2019; Soon et al., 2023).

Types of Adulteration

Food adulteration can be expressed in several types:

1. Physical Adulteration: These are the processes used to change the appearance of food products. For example, mixing a low quality oil with a high quality product.

2. Chemical Adulteration: The addition of harmful substances to the components of food. For example, adding water to frozen fish or dairy products.

3. Illegal Adulteration: Misleading information on food labels can lead consumers to misunderstand food ingredients. Such practices are a violation of food safety laws (Dasenaki & Thomaidis, 2019; Agnoli et al., 2016).

The health effects of food adulteration can be quite serious. The presence of counterfeit or harmful ingredients in foods can lead to foodborne illnesses. Individuals with weak immune systems, children and the elderly are particularly susceptible to such fraud (Creydt & Fischer, 2018). Adulteration can also adversely affect the taste, nutritional value and overall quality of a food.

Economic and Social Impacts

Food fraud can cause economic losses for both consumers and producers. Adulteration leads consumers to purchase unsafe products and undermines brand safety in the food industry (Chang et al., 2022). Adulteration incidents can increase costs for food businesses as recalls and quality control processes may become mandatory.

Solution Suggestions

An effective fight is needed to reduce food adulteration: Strengthening Regulatory Framework: Food safety laws need to be updated and enforced more effectively. Food businesses should be encouraged through continuous inspection and training.

Consumer Awareness: Education programs should inform consumers about food safety. Thus, consumers can better identify fraudulent products.

Transparency: Increasing transparency in food production and distribution is a key step towards rebuilding consumer trust. Food adulteration refers to the fraudulent alteration of food products or the addition of deceptive substances, and this action is usually carried out for economic gain.

## Adulterated Foods and Adulteration Detection Methods

### Adulteration in Olive Oils

Olive oil is an important food product known for its high nutritional value and health benefits. However, olive oil is frequently subjected to adulteration due to its high costs and market-provided qualities. Adulteration can occur in the form of adulteration of olive oil with various low-quality vegetable oils, such as soybean oil, sunflower oil or pea oil (Varnasseri et al., 2021).

Causes of Adulteration

The main reasons for adulteration in olive oil are economic concerns. Producers may resort to such fraudulent methods in order to reduce their costs and increase their profits by mixing cheaper oils instead of the more expensive real olive oil. This situation threatens both the quality and safety of the products offered to consumers (Ok, 2017).

Types of Adulteration

There are several types of adulteration in olive oil:

1. Blending with Low Quality Oils: This is the adulteration of real olive oil with sunflower oil, soybean oil or other low-quality vegetable oils. This trick can be done without changing the appearance and taste of olive oil.

2. Chemical Adulteration: Adding preservatives or harmful chemicals to olive oil. For example, the use of unspecified additives in olive oil that can harm health.

3. Mislabeling: Misleading product labeling can lead consumers to obtain false information about the quality of the product they are purchasing (Varnasseri et al., 2021).

Adulteration Detection Methods

Various analytical methods have been developed for the detection of adulteration in olive oil:

NMR Spectroscopy: Fauhl et al. analyzed blends of olive oil and hazelnut oil using nuclear magnetic resonance (NMR) spectroscopy and were able to detect suspected cases of adulteration with the addition of 25% or more hazelnut oil (Parker et al., 2014).

HPLC and GC: Jabeur and colleagues detected adulteration of olive oil with various vegetable oils using gas chromatography (GC) and liquid chromatography (HPLC) (Jabeur et al., 2014).

Fluorescence and FTIR Spectroscopy: Zhang et al. studied the detection of olive oil adulteration by fluorescence spectroscopy (Zhang et al., 2024).

Consumer Health Impact

Adulteration of olive oil poses serious health risks. Consumption of low-quality oils can cause both loss of nutritional value and health problems such as allergic reactions. Furthermore, consumption of adulterated products can lead to serious social and economic problems by reducing consumer confidence in olive oil in general (İlem-Özdemir & Öztürk, 2020; Nanou et al., 2023).

**Adulteration in dairy products**

Adulteration in dairy products is an important problem in terms of food safety. Adulteration refers to the deliberate addition of low-quality or unhealthy ingredients to milk and dairy products or the misrepresentation of their true value. Dairy products are widely consumed worldwide due to their high nutritional value, making them a target for counterfeiting and adulteration (Montgomery et al., 2020, Tibola et al., 2018).

Types of Adulteration

1. Mixing Animal Species

One of the most common types of adulteration in dairy products is the mixing of cow, sheep or goat milk. In particular, the addition of cow milk into sheep and goat milk is a common fraud. Biçer et al. addressed this situation and emphasized the negative effects of adulteration on milk quality (Biçer et al., 2023).

2. Adding Additives

Illegal additives can be added to dairy products to increase their nutritional value or to reduce costs. For example, glucose, protein powders or other harmful substances are added to dairy products, altering the actual nutritional value (Grassi et al., 2022).

3. Mislabeling

Misleading information on food labels leads to consumer deception. The substitution of genuine dairy products for lower quality or counterfeit products sold as "real" dairy products is one of the most common forms of adulteration (Montgomery et al., 2020).

Health Effects of Adulteration

Adulteration of dairy products can pose serious risks to consumers' health. For example, the addition of harmful chemicals such as melamine or formalin can lead to allergic reactions or other health problems in consumers (Grassi et al., 2022). Consumption of such fraudulent products can lead to an increase in foodborne diseases and pave the way for the development of health problems in the long term.

Detection Methods

Various methods have been developed to prevent and detect adulteration in dairy products. Genetic analysis methods can be used effectively to identify animal species in milk samples. In the study of Biçer and colleagues, TaqMan Real-Time PCR method was used to determine which animal species belonged to which animal species in milk (Biçer et al., 2023). Chemical analysis and various spectroscopy techniques are also used to detect adulteration (Mafra et al., 2022).

Economic Impacts

Adulteration in dairy products can cause economic losses to both consumers and producers. The loss of consumer confidence leads to increased legal and financial liabilities in the market. Adulteration, which is economically motivated, both damages the reputation of food businesses and creates serious problems in healthy food consumption (Tibola et al., 2018; Mafra et al., 2022)

Cheese is an important foodstuff in many cultures with its nutritional properties and flavor. However, adulteration incidents are frequently experienced in cheese production due to economic motivations. Cheese adulteration generally means adding low-quality or unhealthy substances or using imitation products instead of real cheese. This text details the types of adulteration in cheeses, their effects on health and the precautions to be taken.

Types of Adulteration

1. Mixing with Low-Quality Ingredients

A common type of adulteration is the use of vegetable oils or low-quality milk powders instead of milk in cheese production. The health risks of toxic compounds formed by the use of low-quality oils in imitation mozzarella cheese were emphasized in the study by Han and Csallany (2012). While real milk has different nutritional values, imitation cheeses usually offer less nutritional value.

2. False Labeling and Adulteration

Providing misleading information on cheese labels prevents consumers from knowing the real content of the products they buy. The sale of imitation cheeses as "real cheese" is one of the most common such frauds. Studies on this subject are based on information provided on mislabeling, but there is no definitive source here (Liu et al., 2017; Saraco & Blaxland, 2020). Mislabeling can harm consumers' health and is a phenomenon that threatens food safety.

3. Use of Hyaluronic Acid and By-Products

It has been reported that fertilizers derived from microbes are used in some imitation cheeses and these affect product quality; more evidence is needed on this issue. In the study by Padhiyar et al (2017), the effects of different protein sources and costumes used for cheese analogues on cheese quality were examined

Health Effects

The health effects of adulteration in cheeses are extremely serious. Consumption of imitation cheeses can cause allergic reactions, foodborne poisoning and other health problems (Xie et al., 2021). In addition, the addition of illegal chemicals to milk ingredients can pose serious health threats, especially in individuals with weak immune defenses.

Control and Detection Methods

There are various methods that can be used to detect adulteration in cheese:

-Chemical Analyses: Methods such as gas chromatography and liquid chromatography can be effective in determining the fat quality and content in cheese. In a study conducted by El-Bakry and colleagues, the content of imitation cheese was examined by chemical analyses (Mehfooz et al., 2021).

Spectroscopic Methods: Methods such as NMR (Nuclear Magnetic Resonance) spectrum analysis can also be used to detect imitation cheese. Thus, it is possible to understand whether the ingredients in cheese are natural or not (Katidi et al., 2023).

Economic Impacts

Adulteration not only results in health problems, but also in undermining consumer confidence. This situation creates the need to strengthen quality control systems in the cheese sector. The prevalence of adulteration leads to higher cheese prices and market imbalances, which may cause consumers to turn to less safe products (El-Bakry et al., 2010).

**Raising Consumer Awareness Against Fraud and Adulteration**

Fraud and adulteration in food create significant problems both in terms of health and socio-

Fraud and adulteration in food create significant problems both in terms of health and socio-economic aspects. Especially products like cheese, milk, and olive oil are frequently subjected to fraudulent practices. Raising consumer awareness on these issues, making healthy food choices, and preventing such frauds are of critical importance. Below are important topics related to raising consumer awareness against fraud and adulteration.

Definition of Fraud and Adulteration Fraud and adulteration mean the deliberate alteration of the content, quality, and safety of food products. It is important for consumers to understand what types of fraud can be committed in food products in order to raise awareness on this issue (Biçer et al., 2023).

Education and Information Increasing the education levels of consumers will raise their awareness of food safety. Education enables them to be knowledgeable about the properties of foods, label reading skills, and food safety standards. Especially the inclusion of food safety education in school curricula can help young people become more conscious individuals in this field (Bozkurt, 2024).

Labeling and Transparency The accuracy of the information specified on food product labels is of critical importance to the consumer. It is necessary to provide training so that consumers can choose between correctly labeled products and counterfeit ones. To raise consumer awareness, information should be provided on how to read correct labels and which signs increase reliability (Araç et al., 2022).

Social Media and Digital Platforms Social media and digital platforms can be an effective informational tool regarding food safety. Sharing information related to food safety will enable consumers to become more knowledgeable about fraud and adulteration. Social media campaigns can be used to raise awareness on this issue (Duran, 2023).

Collaboration with the Community Local governments, non-governmental organizations, and the ready-to-eat food industry should cooperate in combating fraudulent food products. Public information campaigns are an effective method for raising citizens' awareness levels regarding food safety. Consumer complaints and feedback can be an important resource for improving food safety practices (Biçer et al., 2023).

Strengthening Legal Regulations The government needs to strengthen food safety laws and enhance inspection mechanisms. Effective legal measures need to be developed to protect consumers from counterfeit and adulterated products. In addition, establishing systems that will enhance the traceability of products can help in the quicker detection of adulteration and fraud cases (Çil, 2017)

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Chapter 5

# Antioxidants as Food Additives

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**Abstract**

Antioxidants are essential chemicals that help sustain health and prevent disease. They function by neutralising free radicals, which are unstable chemicals created by the body's normal metabolic processes or by external influences such as pollution, radiation, and cigarette smoke. When free radicals build up, they can create oxidative stress, which harms cells and contributes to ageing and the development of chronic diseases such as heart disease, cancer, and neurological disorders. Antioxidants help to mitigate this damage by stabilising free radicals and keeping them from hurting the body's cells. They are naturally found in a wide range of foods, including fruits, vegetables, nuts, and whole grains. Common antioxidants include vitamins C and E, beta-carotene, selenium, and a spectrum of phytochemicals such as flavonoids.

## 1. Introduction

Antioxidants are a wide range of substances that serve an important function in preventing oxidation, which can cause cellular damage and other chronic diseases. Antioxidants, in their broadest sense, are chemicals that, when present in low concentrations relative to oxidisable substrates, considerably delay or block oxidation processes. They work by scavenging reactive oxygen species (ROS), reducing oxidative stress, which has been linked to a variety of health issues such as cancer, cardiovascular disease, and neurological disorders (Uzombah, 2022; Oliverio et al., 2022).

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Antioxidants are categorised into distinct categories based on their source and their mechanism of action. They can be endogenous (made by the body) or exogenous (obtained through dietary sources). Exogenous antioxidants include dietary components such vitamins C and E, polyphenols, and flavonoids (Sardarodiyan & Sani, 2016). The molecular profile of antioxidants in food can differ from those in dietary supplements; for example, foods may include numerous forms of vitamin E, but supplements frequently contain only one variety (Shebis et al., 2013).

In the food industry, antioxidants are used as additives to extend shelf life and retain sensory properties such as flavour, colour, and nutritional value. Commonly used food antioxidants include both synthetic substances such as butylated hydroxytoluene (BHT) and natural components derived from plants, such as green tea extracts and other fruits (Shahidi & Ambigaipalan, 2015; Souza et al., 2011). These antioxidants act by inhibiting the oxidative destruction of lipids and other sensitive components in food, hence reducing rancidity and the generation of hazardous oxidative products (Souza et al., 2011).

Natural antioxidants are replacing synthetic ones in food systems as a result of growing consumer awareness of health and wellness. In addition to their apparent health advantages, natural antioxidants are favoured because they meet consumer standards for food safety and quality (Uzombah, 2022). Although the use of food additives, such as antioxidants, is governed by regulations, natural sources are frequently subject to less scrutiny than synthetic ones (Franco et al., 2019; Chan, 2014). Customers' demands for products devoid of artificial chemicals are reflected in the food industry's broader movement towards "clean labelling" (Sardarodiyan & Sani, 2016).

### 1.1. Oxidation Reactions of Food Components

Oxidation is a process that involves the loss of electrons, frequently including oxygen, and results in the destruction of important components such as lipids, proteins, and vitamins (Zhou et al., 2022). This process can cause off-flavors, odours, colour changes, and hazardous chemicals, making it a major problem in food science (Duque-Estrada et al., 2019; Shahidi & Zhong, 2010).

Oxidation of food is a chemical process that occurs when food components, mainly fats, oils, and some vitamins, react with airborne oxygen. This reaction can cause changes in the flavour, colour, texture, and nutritional quality of the food. One of the most visible and prevalent results of oxidation is rancidity in fats and oils, which gives food an unpleasant taste and odour.

Lipid oxidation, which is mostly caused unsaturated fatty acids present in oils and fats, is one of the important components of food oxidation. Rancidity and unwanted flavours can result from production of hydroperoxides, which break down into a variety of volatile chemicals (Zhou et al., 2022). Temperature, oxygen exposure, and light can all accelerate the rate of lipid oxidation, which happens regularly during food processing, storage, and cooking (Gümüş & Decker, 2021; Osawa et al., 2008). For example, lipid-rich foods that undergo oxidative deterioration may produce toxic compounds called advanced lipid oxidation end products (ALEs), which have been associated with negative health effects when ingested (Kanner, 2007; Shahidi & Zhong, 2010).

Protein oxidation is another important topic in the research of food oxidation. Heat, light, and metal ions may all cause this process, which results in structural alterations in proteins. These alterations can cause the development of protein carbonyls and reactive species, such as dityrosine, affecting the sensory qualities and nutritional quality of food (Li et al., 2022; Lund et al., 2010). Protein oxidation not only reduces solubility and functioning, but it can also produce toxic chemicals that endanger human health, such as those that disrupt thyroid function and contribute to degenerative disorders (Li et al., 2022; Hellwig, 2019).

Furthermore, oxidation can influence the Maillard reaction, which happens during processing when amino acids and reducing sugars react together. Although this reaction can produce attractive flavours and colours in cooked foods, excessive oxidation can produce undesirable and potentially dangerous compounds (Poojary and Lund, 2022). Maintaining a balance between good and undesirable oxidative changes during food production is critical.

Antioxidants have a well-established role in reducing these oxidation processes, according to both scientific literature and food industry standards. By scavenging free radicals, natural antioxidants such polyphenols, vitamins, and carotenoids can slow down oxidation reactions and increase the shelf life of food (Santoro et al., 2022). By lowering oxidative stress linked to a number of illnesses, the prudent use of these antioxidants not only preserves food but may also help consumers' health (Franco et al., 2016).

## 1.2. Classification of Antioxidants

Antioxidants are categorised into different types depending on their origin, solubility, method of action, and chemical composition. Understanding these classifications assists in determining their significance in food preservation, health advantages, and use in the food industry.

***Origin:***

Natural antioxidants: They come from plant and animal sources. Common examples include vitamins (such as vitamin C and E), flavonoids, polyphenols, and carotenoids, all of which have been linked to improved health. These antioxidants are frequently perceived as safer and healthier than synthetic alternatives (Uzombah, 2022).

Synthetic Antioxidants: These are substances that are made artificially with the intention of preventing oxidation. Tert-butylhydroquinone (TBHQ), butylated hydroxytoluene (BHT), and butylated hydroxyanisole (BHA) are examples of common synthetic antioxidants. Despite their effectiveness in food preservation, there are growing worries about the possible health consequences of consuming them (Ashwar et al., 2014; Kebede & Admassu, 2019).

***Mechanism of Action:***

Free Radical Scavengers: These antioxidants work by directly scavenging free radicals, which are oxidatively damaging chemicals. Vitamins C and E are two examples (Peng et al., 2014).

Breaking chains Antioxidants: These substances efficiently stop the oxidation chain reaction by interfering with it. In this category, phenolic chemicals are prevalent (Shahidi & Ambigaipalan, 2015).

Reducing Agents: This class of antioxidant maintains the integrity of biomolecules by returning oxidised species to their initial condition. One significant endogenous antioxidant in this class is glutathione (Peng et al., 2014).

***Solubility:***

Hydrophilic Antioxidants: These antioxidants are water-soluble and are found largely in the watery environs of cells. Examples include vitamin C and a wide variety of polyphenolic chemicals (Carlsen et al., 2010).

Lipophilic antioxidants: These fat-soluble antioxidants can suppress lipid oxidation in cell membranes and lipid-rich foods. Carotenoids and vitamin E are two important examples (Madhab et al., 2023; Chen et al., 2012).

***Chemical Composition:***

Phenolic Compounds: This category includes a wide range of compounds, including flavonoids, tannins, and simple phenols, which have been recognised for their strong antioxidant properties and ability to scavenge free radicals (Shahidi and Ambigaipalan, 2015).

Vitamins: Vitamin C (ascorbic acid) and vitamin E (tocopherols and tocotrienols) are important antioxidants that protect cellular components from oxidative stress (Madhab et al., 2023; Peng et al., 2014).

Minerals: Some minerals, such as selenium and zinc, are required for the formation of antioxidant enzymes such as superoxide dismutase and glutathione peroxidase, which contribute to the body's natural antioxidative defence systems (Kebede & Admassu, 2019; Peng et al., 2014).

***Application-Based Classification:***

Antioxidants are routinely added to food goods to extend shelf life and prevent spoiling caused by oxidation. Synthetic chemicals like BHA and BHT are widely used, while natural antioxidants found in spices and herbs can also improve food quality (Poljšak et al., 2021; Bolchini et al., 2025).

Active Packaging: Recent advances in food technology have resulted in the introduction of packaging materials containing antioxidants. These active packaging technologies can increase shelf life by slowly releasing antioxidants into the food environment (Fasihnia et al., 2020).

## 1.3. Mechanism of antioxidants on oxidation reaction

Antioxidants serve a critical role in limiting oxidative damage by interfering in diverse oxidative processes via distinct methods. These processes include free radical scavenging, metal chelation, and other specialised antioxidant reactions, all of which contribute to their effectiveness in stabilising or deactivating reactive species.

***Free Radical Scavenging:*** Scavenging free radicals is one of the primary mechanisms by which antioxidants exert their beneficial effects. Free radicals, including alkylperoxyl radicals and superoxide, are extremely reactive species that can cause oxidative damage in biomolecules (Arora et al., 2000). Antioxidants provide electrons to these radical entities, neutralising and converting them into more stable, less reactive states. For example, genistein has been shown to react with peroxyl radicals primarily at its B-ring, suggesting that certain antioxidant structural characteristics enhance their radical-scavenging activity (Arora et al., 2000). Green tea catechins predominantly exhibit antioxidant action by enhancing radical scavenging capacities (Janeiro & Oliveira-Brett, 2004).

***Metal Chelation:*** Antioxidants also limit oxidation by chelating metal ions like iron and copper, which can catalyse the creation of reactive oxygen species. This technique significantly reduces metal availability for oxidation processes. Flavonoids, for example, have high metal-chelating characteristics because their complex molecular structures bind to metal ions and prevent them from participating in oxidative processes (Sontakke et al., 2020). Caffeic acid, for example, has been shown to form stable complexes with ferric ions, lowering oxidative stress by sequestering pro-oxidant metal ions that would otherwise promote free radical generation (Masuda et al., 2008).

***Oxygen Quenching in Singlets***

Another powerful oxidiser that can harm lipids, proteins, and nucleic acids is singlet oxygen, a high-energy form of oxygen (Gülçın et al., 2005). In order to prevent the damaging effects of singlet oxygen, antioxidants efficiently quench it, frequently by means of energy transfer processes that return dangerous singlet oxygen to its triplet state (Cheng, 2016). Because of their structured polyene backbone, which offers multiple sites for interaction, carotenoids, for instance, have shown notable effectiveness in singlet oxygen quenching (Cheng, 2016). As a vital lipid-soluble antioxidant in protective cellular membranes, vitamin E is also known for its capacity to scavenge singlet oxygen (Nazıroğlu & Butterworth, 2005).

### 1.4. Applications of antioxidants in Food Products

Antioxidants serve critical functions in food preservation by enhancing shelf life, improving nutritional value, and retaining sensory qualities. They are employed across various food categories, including oils, meat products, dairy, baked goods, beverages, and packaged foods.

***Oils***

Antioxidants extend shelf life and preserve quality in the field of edible oils by preventing oxidative degradation. For example, it has been demonstrated that adding oregano essential oil to extra-virgin olive oil improves its oxidative stability while being stored, thereby shielding it from lipid peroxidation (Asensio et al., 2011). Furthermore, studies show that toasting sesame seeds raises their phenolic content, which enhances sesame oil's antioxidant potential (Shi et al., 2017). Many studies have looked into the effectiveness of natural antioxidants including butylated hydroxytoluene (BHT) and rosemary extract in stabilising different types of cooking oils (Okhli et al., 2020; Soydan & Erdoğan, 2019).

Grape pomace extracts used in grapeseed oil are examples of environmentally friendly extracts that improve oxidative stability, demonstrating potential advantages in food processing and also promoting agricultural sustainability (Cisneros-Yupanqui et al., 2024). Superior antioxidant qualities of high-phenolic olive oil help to lessen the negative effects of oxidative stress on human health (Liu et al., 2019).

***Meat products***

Antioxidants are especially important in meat preservation because they prevent lipid oxidation and off-flavor formation. Incorporating rosemary diterpenes in lamb diets improves antioxidant status and reduces oxidation rates (Ortuño et al., 2016). Furthermore, the use of natural antioxidant extracts obtained from plant sources is being researched as a means of replacing synthetic chemicals in meat production (Lee et al., 2020). Natural extracts, for example, have shown promise in improving the stability and quality of processed meats (Lee et al. 2020). According to Vulić et al. (2024), ascorbic and citric acids are effective antioxidants that can enhance the colour and shelf life of beef products. Antioxidants preserve fatty acid profiles from oxidation, ensuring meat remains tasty and healthy over time.

***Dairy products***

Antioxidants in dairy products function similarly to those in fats and oils, reducing rancidity and preserving flavour integrity. Studies have shown that adding natural antioxidants can successfully stabilise dairy emulsions (Abreu et al., 2011). Incorporating effective antioxidants into processed cheese, for example, can help preserve quality during storage, prolonging both shelf life and sensory qualities (Abreu et al., 2011).

***Baked Products***

The usage of antioxidants in baked goods is crucial for enhancing dough stability and reducing oxidative deterioration of lipids found in formulations. Antioxidants like alpha-tocopherol and ascorbic acid are often employed to improve the oxidative stability of the fats and oils used in bread products, which has a substantial impact on the staling process and overall product quality (Dwyer et al., 2012). Furthermore, using antioxidant-rich plant extracts into baked goods can improve both shelf life and nutritional value.

***Beverages***

Antioxidants are used in the beverage industry, namely in juices and teas, to prevent colour degradation and flavour loss during processing and storage. For example, green tea extracts high in catechins have been shown to stabilise lipid profiles in omega-3 oils when included into emulsified products (Dwyer et al., 2012). They can also be added to fruit-based drinks to boost antioxidant levels, resulting in health benefits when consumed (Song et al., 2010).

***Packaged Foods***

Active packaging techniques that include antioxidants are gaining popularity in the food industry. These systems progressively release antioxidants to fight oxidative processes in food products during their shelf life. Research has shown that packaging materials impregnated with natural antioxidants can maintain freshness in ready-to-eat foods while reducing rancidity (Chacha et al., 2022; Marcos et al., 2014). Biodegradable films with antioxidants, including α-tocopherol, provide both preservation and environmental benefits (Marcos et al., 2014).

### 1.5. Legal regulations and limit values about antioxidant using in food industry

The legal regulations and limit values for the use of antioxidants in the food industry varied extensively among global countries. Regulatory authorities such as the FDA in the United States, the EFSA in Europe, and international frameworks like the Codex Alimentarius provide critical recommendations for food safety, efficacy, and labelling of food additives, including antioxidants.

Under the Federal Food, Drug, and Cosmetic Act, the FDA oversees the regulation of food additives in the US, including antioxidants. Antioxidants can be designated as "generally recognised as safe" (GRAS) or require safety testing before being approved as food additives. Limit values have been set for synthetic antioxidants such as Butylated Hydroxy Toluene (BHT), Butylated Hydroxyanisole (BHA), and Propyl Gallate. For example, BHA is permitted in food products at doses of up to 0.02% (Frazzoli et al., 2023). To avoid deceiving consumers, health claims for antioxidants must follow FDA standards and be validated by scientific evidence (Hegazı et al., 2023).

The EFSA in Europe assesses the effectiveness and safety of food additives, such as antioxidants. Food additives Regulation (EC) No. 1333/2008 establishes the regulatory framework. A list of approved food additives is provided by this rule, along with particular limit values for certain antioxidants. For instance, depending on how they are used, the maximum permitted amounts of specific antioxidants in food categories might be established at varying levels. For instance, some antioxidants in processed foods may have a maximum of 0.01% (El-Batal et al., 2023).

According to Silva et al. (2013), the EFSA also mandates thorough research to evaluate the impact of antioxidants on human health, connecting their use to exposure-based safety evaluations.

The FAO and WHO created the Codex Alimentarius, which sets food standards worldwide, including antioxidant guidelines. To ensure that food additives, including antioxidants, do not present health concerns, the Codex Committee on Food Additives (CCFA) sets permissible limits. Member nations are expected to incorporate these requirements into their domestic laws. In order to facilitate trade and improve consumer safety in food products, Codex offers a methodical approach to the evaluation of food additives with a focus on international harmonisation (Mrdovć et al., 2023).

In Asia, regulatory regimes can vary greatly. For example, in China, the National Health Commission establishes particular restrictions for the use of antioxidants in food, which are frequently consistent with Codex recommendations while also addressing local health issues. The General Administration of Quality Supervision, Inspection, and Quarantine (AQSIQ) provides guidelines for permissible antioxidant levels in several food categories (Talari et al., 2017). Similarly, countries like India have particular standards that set limitations for certain antioxidants based on their classification as permitted food additives (Belesky, 2019).

In Africa, food additive laws, including antioxidants, are not universal and vary by nation. Some African countries' regulatory systems are focused on guaranteeing the safety and efficacy of food products, with Codex criteria being used to define permitted antioxidant levels, particularly in traditional and processed foods (Judakı et al., 2017). The African Organisation for Standardisation (ARSO) also helps to set standards across the continent (Xiao et al., 2020).

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Chapter 6

# Sourdough Fermentation And Microbiome

**Ayşe Sevgili**[1]

**Abstract**

The history of sourdough bread production dates back to ancient times. This bread, which has a high nutritional value, has been replaced by breads produced with baker's yeast over time. In recent years, demand for sourdough bread, which is rich in nutrients, has a low glycemic index and has high mineral absorption, has increased. Sourdough generally contains lactic acid bacteria and yeast microbial groups. *Lactobacillus, Pediococcus* and *Leuconostoc* species are common. These bacteria reduce pH through acid production, increase microbial safety and contribute to aroma formation. Yeast species such as *Saccharomyces cerevisiae, Candida milleri, Kazachstania exigua, Pichia kudriavzevii* ferment carbohydrates and produce $CO_2$ and ethanol. This gas production allows the dough to rise. In this context, fermentation and microbiota of sourdough were examined.

## 1. Introduction

Sourdough (SD) represents one of the oldest methods for producing cereal-based foods, with its origins dating back to ancient civilizations (Islam and Islam, 2024; De Vuyst and Neysens, 2005). The application of the SD process in its role as a leavening agent is considered one of the oldest biotechnological methods used in the processing of food (Arendt et al., 2007). When we look at the Egyptians, we see that they were the first to use beer foam as a leavening agent in bread making, and SD has become a traditional method for baking bread. In the bread production, SD was employed as a leavening agent until the introduction of baking yeast species (baker's yeast) in the early 1900s, when it was replaced by baker's yeast, after which time its use declined and it became associated mainly with handmade and rye bread (Carnevali et al., 2007; Corsetti and Settanni, 2007). SD bread has gained popularity in recent years due to its health and nutritional

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benefits. This reveals the importance of SD microbiota for production SD bread.

The SD ecosystem is characterized by a mixture of flour and water that is exposed to the process of fermentation by yeasts and lactic acid bacteria (LAB) (De Vuyst et al., 2014). The purpose of the SD fermentation was to facilitate the growth of yeasts and heterofermentative lactobacilli, thereby ensuring that enough $CO_2$ is produced for effective dough leavening (Brandt, 2007). The item originates from a SD 'starter culture' that is carefully maintained, portioned, and shared with bread bakers worldwide. A starter culture is composed of a diverse range of microorganisms, specifically bacteria and yeasts, which engage in the fermentation of flour's carbohydrates, resulting in the production of $CO_2$ that facilitates the rising of the bread dough before it is baked (Landis et al., 2021).

Yeasts act as the main leavening agent in bread-making by generating $CO_2$ as a metabolic by-product. Bacteria play a significant role in determining starter acidity through the production of organic acids as metabolic by-products, as well as influencing volatile organic compounds and various other attributes (Calvert et al., 2021). The process of preparing SD involves combining water and flour, followed by fermentation using both homofermentative and heterofermentative LAB. This fermentation leads to an rise in the concentrations of acetic and lactic acids, ultimately resulting in a product with a sour flavor (Sakandar et al., 2019). Yeast growth is restricted due to the acidic conditions that are predominantly established by LAB. As a result, LAB counts ($\geq 10^8$ CFU/g) are significantly greater than those of yeast ($\leq 10^7$ CFU/g), leading to a common ratio of LAB to yeast of approximately 10:1 to 100:1 (Fekri et al., 2024). As a traditional and natural process, lactic acid fermentation serves as a sustainable and efficient means of promoting hygiene, improving rheological characteristics, enhancing sensory qualities, and extending shelf life, in addition to elevating the functional and nutritional value of numerous animal and plant foods and drinks (Gobbetti et al., 2019).

## 2. SD Types and SD Fermentation

The classification of SD fermentation can be based on the type of inoculum, which includes types I, II, and III, as well as the technological processes, categorized into types 0, I, II, and III (Akamine et al., 2023). Based on production methods and processes, SD is categorized into four distinct types: Type I (traditional SD), Type II (starter culture-initiated SD), Type III (dried SD), and Type IV (mixed dried). Both industrial and traditional approaches utilize these four types of SD production. Traditional SD is classified into type I and type II, depending on the procedures utilized in its production (Akamine et al., 2023; Fekri et al., 2024). The basic type 0 fermentation process initiates with a combination of flour and water, which is allowed to ferment for a brief period. The LAB naturally occurring in the flour exhibit faster growth rates and greater abundance compared to yeast (Akamine et al., 2023).

### 2.1. SD Types

The classification of SD into four categories is determined by the fermentation method and the technological strategy that is implemented (Akamine et al., 2023; Islam and Islam, 2024):

**Type I SD;** Type I SD's are made through traditional techniques and are noted for their continuous daily feedings that keep the microorganisms in a state of activity. This is demonstrated by a high level of metabolic activity, particularly in terms of leavening, which refers to the production of gas (Vuyst and Neysens, 2005).

**Type II SD;** the liquid SD could serve as an effective means to customize bread quality, enabling the production of an industrial product with unique characteristics (Carnevali et al., 2007).

**Type III SD;** SD can be dehydrated. This variety of SD is commonly employed by industrial bakeries because it offers a stable quality, thereby preventing inconsistencies in the end product that may occur with freshly prepared SD (Decock and Cappelle, 2005).

**Type IV SD;** type IV represents a laboratory-scale combination of type I and type II SD. In comparison to freshly made SD, type III SD is more user-friendly and provides enhanced storage convenience. This feature supports standardized industrial production and reduces the need for maintaining SD starters (Islam and Islam, 2024).

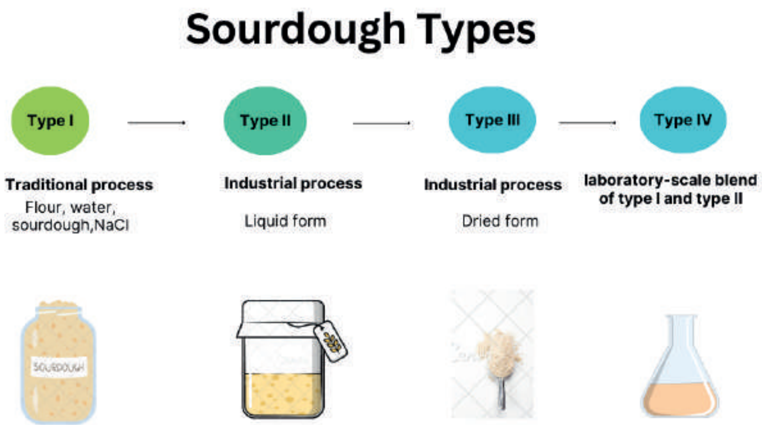


*Figure 1 Scheme of SD production processes*

## 2.2. SD Fermentation

During the SD fermentation process, the predominant byproducts include alcohols, acids, esters, aldehydes, and ketones, which represent the principal means of producing volatile organic compounds. The complexity of SD bread's profile is largely determined by the compounds created during fermentation, which are influenced by a wide range of microorganisms, predominantly yeasts and LAB (Akamine et al., 2023). The primary component of wheat flour is starch, which accounts for approximately 70–75% of its composition. Additionally, it contains around 14% water and 10–12% proteins. Minor constituents, such as non-starch polysaccharides (about 2–3%), particularly arabinoxylans, and lipids (approximately 2%), also have a crucial impact on the production and bread quality (Goesaert et al., 2005). The effects of SD fermentation are linked to the production of organic acids, the stimulation of endogenous enzymes in flour, and the activity of microbial secondary metabolism (Graça et al., 2021). SD fermentation typically takes place in conditions of restricted aeration and is characterized by a sequence of LAB and yeast activity (Hernández-Parada et al., 2022). SD consists of a diverse array of fermentation organisms. Nevertheless, when a specific area is colonized repeatedly (more than 10 times) over an extended duration, it typically develops a stable microbial community structure (Ma et al., 2021). SD is crucial in the field of baking technology, contributing to improvements in aroma, texture, shelf life, and the availability of minerals for absorption (Galle and Arendt, 2014). The diversity of microbial species in SD, especially in terms of phylogenetic variety, is restricted. This includes yeasts from the Ascomycota phylum, LAB primarily from the Firmicutes group, particularly the Lactobacillaceae family, and occasionally acetic acid bacteria belonging to the α-proteobacteria class (De Vuyst et al., 2023).

During the fermentation process, the concentration of glucose rises as LAB and yeasts metabolize various complex carbohydrates (Akamine et al., 2023). In addition to maltose, the SD matrix comprises sucrose, glucose—produced by the action of endogenous amylase in flour and the breakdown of glucofructans by yeast—and fructose, which is generated from glucofructans through yeast activity. It is well-established that numerous LAB isolates from SD exhibit facultative heterofermentative characteristics (Weckx et al., 2019). Amino acids play a role as substrates for microbial conversions or are converted into flavor compounds in the baking process; therefore, a limited degree of proteolysis during fermentation can enhance the flavor of the bread (Gänzle et al., 2008).

The assessment of SD fermentation typically involves the analysis of various parameters, including acidity, pH levels, and the composition of microflora (Wick et al., 2003). Additionally, temperature is a crucial factor affecting the microflora in SD. For instance, when fermentation occurs at temperatures exceeding 30°C, homofermentative and facultative heterofermentative lactobacilli, such as *Lactobacillus fermentum* (*L. fermentum*) and *L. plantarum*, are more prevalent. Conversely, at temperatures below 30°C, heterofermentative lactobacilli like *L. sanfranciscensis* become dominant. It is important to note that, alongside temperature, dough hydration is also a key parameter that influences the fermentation process of SD (Casado et al., 2017).

In SD, a complex community of microorganisms is invariably present, and the dynamics between LAB and yeast significantly influence the qualities of the final product (Fu et al., 2024). Different types of yeasts and LAB, including both homofermentative and heterofermentative strains, have varying effects on the attributes of SD (Gianotti et al., 1997). The production of diverse aromatic compounds by yeasts plays a crucial role in creating balanced flavors in bread, particularly when paired with acids. In contrast, yeasts in SD demonstrate a capacity to thrive in stressful environments marked by low pH, high carbohydrate levels, and a significant presence of LAB (Hernández-Parada et al., 2022). In SD bread, LAB generates lower levels of volatile compounds compared to yeast. The activity of microbial or wheat proteases during lactic fermentation leads to the release of amino acids (Meignen et al., 2001). The fermentation of cereal SD involves the release of oligopeptides primarily due to the activity of cereal endoproteases during the primary stage of proteolysis. Conversely, the generation of smaller peptides and free amino acids is a result of the secondary metabolic activity of microbial peptidases, particularly from LAB (Graça et al., 2021). Fermentation occurs through two principal pathways: alcoholic fermentation and lactic fermentation. In the case of lactic fermentation, pyruvate molecules produced from glucose oxidation via the Embden–Meyerhof–Parnas (EMP) or glycolytic pathway are reduced to lactic acid, a process termed homolactic fermentation. This pathway is employed by bacteria such as *Streptococcus, Lactobacillus*, and *Enterococcus*. Alternatively, pyruvate can be derived from a combination of lactate, ethanol, and/or acetic acid, which is facilitated by the oxidation of coenzymes NADH + and H+ by lactate dehydrogenase, along with the release of $CO_2$ from glucose until it reaches ribulose 5-phosphate, known as heterolactic fermentation (Akamine et al., 2023).

Homofermentative LAB are capable of nearly entirely converting hexoses into lactic acid, achieving rates greater than 85%. Conversely, heterofermentative LAB process hexoses into a combination of acetic acid or ethanol, lactic acid, and carbon dioxide. The ratio of acetic acid to lactic acid is influenced not only by the choice of starter culture but also by the fermentation temperature. Moreover, heterofermentative LAB can synthesize both lactic and acetic acid from pentose sugars (Hansen and Schieberle, 2005). SD fermentation involves the action of LAB, which moderately hydrolyze starch, conduct proteolysis, and acidify the dough. These processes yield a soft and flavorful crumb, improve the bioavailability of minerals through the degradation of phytates, and prevent the growth of microorganisms that lead to spoilage (Hernández-Parada et al., 2022). The generation of exopolysaccharides (EPS) by LAB during SD fermentation contributes to improved bread volume and texture, in addition to elevating the dietary fiber levels (Gänzle, 2014).

Research on the function of LAB in protein metabolism during fermentation has predominantly focused on two specific profiles:

(1) improving the solubility of insoluble components by means of acidification and the regeneration of glutathione;

(2) the process of hydrolyzing native proteins in flour using proteinase and peptidase enzymes (Fu et al., 2024).

Initially, maltose is preferentially fermented through the action of a constitutively expressed and energy-efficient maltose phosphorylase. This fermentation process is not inhibited by glucose and does not prevent growth of yeast. This is attributed to the synergistic relationship between maltose phosphorylase-positive heterofermentative LAB species, such as *Frul. sanfranciscensis*, *Liml. fermentum*, and *Liml. reuteri*, and maltose-negative yeasts, particularly *K. humilis*, within the SD environment (De Vuyst et al., 2023).

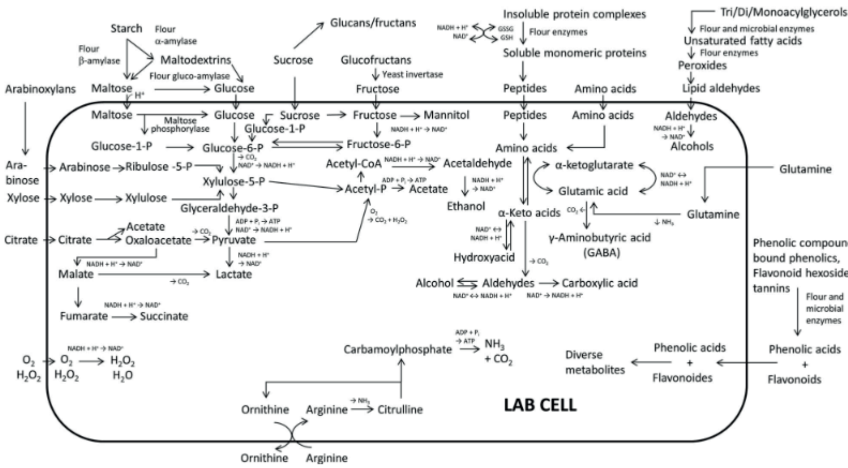


***Figure 2 Overview of the metabolic activities of LAB species in the context of a SD matrix (De Vuyst et al., 2023)***

SD yeasts metabolize the saccharides present in flour, including maltose, glucose, sucrose, and fructose, through the EMP pathway, resulting in the production of pyruvate. This process generates adenosine triphosphate and reducing equivalents in the form of NADH and H+. Subsequently, pyruvate is transformed into ethanol and $CO_2$ during alcoholic fermentation, which also replenishes the NAD+ cofactor that was utilized earlier in the EMP pathway (De Vuyst et al., 2023). Homofermentative LAB primarily convert glucose into lactic acid via glycolysis, a process known as homolactic fermentation. In contrast, heterofermentative LAB not only generate lactic acid but also produce $CO_2$, acetic acid, and/or ethanol, contingent upon the availability of supplementary substrates that serve as electron acceptors, particularly in the case of *Lactobacillus sanfranciscensis*. This occurs through the 6-phosphogluconate/phosphoketolase (6-PG/PK) pathway, which characterizes heterolactic fermentation (Corsetti and Settanni, 2007). By producing metabolites such as esters, aldehydes, and acetoin, yeasts play an important role in enhancing the flavor profile of bread (Hernández-Parada et al., 2022).

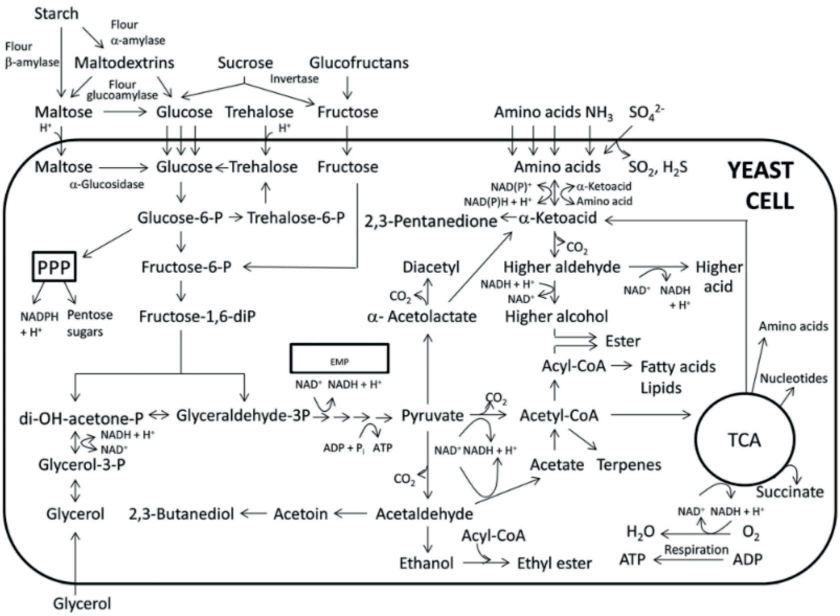


*Figure 3 Overview of the metabolic activities of yeasts species in the context of a SD matrix (De Vuyst et al., 2023)*

The presence and significance of various microorganisms in SD:

- The principal carbon sources utilized by *Pediococcus acidilactici* were glucose and fructose (Fu et al., 2024).
- The presence of *L. plantarum* is commonly observed in conjunction with *Lactobacillus fermentum* in the spontaneous fermentation processes of cereal products (Coda et al., 2014).
- Previous research indicates that *L. plantarum* is frequently present in the ecosystems of SD's (De Vuyst and Neysens, 2005).
- Isolated from SD fermentation, the strains *L. plantarum* ES137 and *P. acidilactici* ES22 exhibited a remarkable ability to break down proteins (Akamine et al., 2023).
- In SD's with a high pH level (exceeding 4.0), heterofermentative *Leuconostoc* and *Weissella* are commonly present, particularly when fermentation occurs at low temperatures (below 30 °C) and with a low dough yield (less than 200) (De Vuyst et al., 2023).

- It has been established that *L. brevis* subsp. *lindneri* and *L. plantarum* exhibit the most appropriate flavor component profiles (Paterson and Piggott, 2006).

**Enzymes:** The enzymatic processes of LAB and yeast during SD fermentation are increasingly understood. Hydrolases play a crucial role in the production of SD bread. Additionally, other classes of enzymes, such as transferases and oxidoreductases, contribute to the characteristics of SD fermentation (Akamine et al., 2023). Transferases, oxidoreductases, lyases and hydrolases are enzymes involved in SD production.

**EPS:** The EPS synthesized by LAB have the potential to enhance both the rheological behavior of dough and the quality of bread texture. This indicates that EPS from LAB could be utilized to substitute or diminish the reliance on pricier hydrocolloids that are typically used to improve bread texture. Furthermore, some LAB-produced EPS are known to possess prebiotic properties (Arendt et al., 2007). EPS like β-glucan, dextran, and inulin are metabolites produced by LAB during the fermentation of SD. β-glucan, in particular, is a prebiotic homopolysaccharide composed of glucose, which offers significant health advantages, including the regulation of cholesterol levels, anti-inflammatory properties, and support for probiotic microorganisms (Akamine et al, 2023).

**Gluten:** Gluten is a crucial protein complex that plays a significant role in determining the quality and structural integrity of products made from wheat (Nionelli and Rizzello, 2016). According to Poutanen et al., (2009), the breakdown of cereal proteins during the fermentation of wheat and rye SD is closely linked to acidity, significantly influencing both the flavor and texture of the resulting bread. The acidification process and the reduction of disulfide bonds in gluten, mediated by heterofermentative lactobacilli, result in increased cereal protease activity and enhanced substrate accessibility. Moreover, strain-specific intracellular peptidases from lactobacilli play a crucial role in the accumulation of amino acids. Germinated cereals and specific proteases promote a thorough degradation of proteins in SD's throughout fermentation protocols, potentially leading to the development of innovative products for individuals suffering from gluten intolerance.

**Aroma and taste:** SD fermentation generates two types of flavor compounds. The first category consists of non-volatile compounds, such as organic acids, which are produced by both homofermentative and heterofermentative bacteria. These compounds play a crucial role in acidifying the dough, lowering its pH, and enhancing its aroma (Paterson and Piggott, 2006). In SD bread, flavor-active compounds are generated both by LAB and yeasts, as well as through their interactions. Heterofermentative LAB primarily generate ethyl acetate along with various alcohols and aldehydes, while homofermentative LAB are responsible for the production of diacetyl and other carbonyl compounds. Conversely, iso-alcohols arise from yeast fermentation, although they contribute minimally to the overall flavor of the finished bread (Paterson et al.,2006).

## 3. SD Microbiome

The group of SD lactobacilli, comprising obligate and facultative heterofermentative species alongside obligate homofermentative species (see Table 1), is associated with type I, type II, and type III SD's, in addition to type 0 dough. Type 0 dough, characterized by the use of baker's yeast as the main fermenting agent, is not created using SD processes (Corsetti and Settanni, 2007). Table 1 outlines the LAB and yeasts that are typically found in SD. The yeasts identified in SD represent a diversity of over 20 species (Corsetti and Settanni, 2007). The frequently dominant *Saccharomyces cerevisiae (S. cerevisiae) (Corsetti and Settanni, 2007)*. In a systematic examination spanning from 1990 to 2020, Arora et al. (2021) identified the following article counts by geographic area using "sourdough" as a keyword: North America (13), South America (6), Africa (31), Europe (175), Asia (54), China (20), and Oceania (1, specifically New Zealand). In Latin America and America, very few studies have been published. *Lactobacillus plantarum* and *Saccharomyces cerevisiae* appeared in several SD microbiota characterizations (Arora et al., 2021). Additionally, the timeline for the literature review in this research commenced with the initial isolation of yeasts from SD sourced from various regions in Türkiye. This was achieved through the use of keywords including "sourdough," "yeast isolation from sourdough," "sourdough microbiota," and "yeast from sourdough," as indicated by Sevgili and Erkmen in 2024. The findings of their research indicate that the literature reveals the greatest diversity of species was identified in the Central Anatolia Region, the Mediterranean Sea, and the Aegean Region. In all these areas, *S. cerevisiae* emerged as the most frequently isolated yeast, followed by *Torulaspora delbrueckii* and *Pichia guilliermondii* as the next most commonly isolated species.

In particular, the microorganisms *L. plantarum, L. sanfranciscensis, L. pontis*, and *L. panis* are considered fundamental to the SD fermentation process (Arendt et al., 2007). According to (Van Kerrebroeck et al., 2017) study, in general, the most prevalent LAB species are *L. sanfranciscensis* (belonging to the *Lactobacillus fructivorans* group), *L. plantarum* (*Lb. plantarum* group), *L. brevis* (*Lb. brevis* group), *P. pentosaceus* (pediococci), *L. paralimentarius* (*Lactobacillus alimentarius* group), and *L. fermentum* (*Lactobacillus reuteri* group). Some varieties of SD are known to include *Leuconostoc* and *Weissella* species. The most common yeast species present are *Candida humilis*, now reclassified as *Kazachstania humilis*, alongside other members of the *Kazachstania* clade, in addition to *S. cerevisiae* from the *Saccharomyces* clade (Van Kerrebroeck et al., 2017).

The research conducted by Gänzle and Zheng (2019) indicates that the literature on the 227 SD's categorized as type I primarily comprises samples from Italy, France, Germany, Belgium, the United States, and Canada. Since 2015, information has also emerged regarding the use of Chinese SD's in the production of steamed bread. Notably, over 95% of these SD's were found to contain heterofermentative LAB, either exclusively or in combination with homofermentative lactobacilli. *L. sanfranciscensis* was the most commonly found species, present in 178 out of 227 SD samples. Other notable species included *L. plantarum* and *L. brevis*, as well as several members of the *L. alimentarius* group, such as *L. paralimentarius, L. crustorum, L. mindensis*, and *L. nantensis*. Additionally, *Leuconostoc* spp. and *Weissella* spp. were also identified. Among the SD samples, five were kept at the household level, where the fermentation process was temporarily halted due to refrigeration for periods ranging from several days to weeks. Each of these SD's contained a mixture of *L. plantarum* and *L. brevis*. The literature pertaining to the 32 SD's categorized as type II primarily featured rye SD's from Finland, Estonia, Denmark, and Germany, with some data also available for a limited number of wheat SD's from the United States, China, and France. Type II SD's were found to contain heterofermentative microorganisms, either independently or in combination with homofermentative lactobacilli. Notable species from the *L. reuteri* group, such as *L. pontis, L. panis, L. frumenti*, and *L. reuteri*, along with members of the *L. delbrueckii* group, including *L. amylovorus, L. crispatus*, and *L. acidophilus*, were commonly detected in these type II SD's. Additionally, *L. sanfranciscensis* was identified in three Chinese SD's utilized for dough acidification alongside baker's yeast (Gänzle and Zheng, 2019).

Sevgili et al. (2021) worked on isolation of SD from collected Gaziantep, Konya and Mardin. They are identified as *L. brevis, L. plantarum, P. acidilactici, L. paraplantarum, L. pentosus, Enterococcus faecalis, L. paralimentarius, Weissella confusa, Leuconostoc mesenteroides* subsp. *mesenteroides, Leuconostoc mesenteroides* subsp. *cremoris* and *Enterococcus hirae* in LAB. They are identified as *Pichia kudriavzevii, Kluyveromyces marxianus, S. cerevisiae, Wickerhamomyces anomalus*, *Kazachstania humilis, Candida glabrata, Geotrichum candidum, Kazachstania unispora, Galactomyces candidum, Candida kefyr* and *Candida tropicalis* in yeasts.

According to Weckx et al., (2019) study, the dominant species of LAB are primarily heterofermentative, including *L. sanfranciscensis, L. plantarum* (which is facultatively heterofermentative), *L. brevis*, and *P. pentosaceus* (which is homofermentative). Additionally, *L. paralimentarius* (facultatively heterofermentative) and *L. fermentum* are also notable. In contrast, the most common yeast species are *Kazachstania humilis* (previously known as *Candida humilis* and *Candida milleri*) and *S. cerevisiae*. The composition of minor communities consists of different *Lactobacillus* species, like *L. reuteri* and *L. rossiae*, in conjunction with species from the LAB genera *Leuconostoc* and *Weissella*, as well as various yeast species from the *Kazachstania* clade (Weckx et al., 2019).

***Table 1 Some microbiome as Type I, II and III (yeasts and bacteria) of different SD types (Gänzle and Zheng., (2019); De Marco et al., (2022); Teixeira et al., (2024))***

| Type I | Type II | Type III* |
|---|---|---|
| *L. sanfranciscensis* | *L. reuteri* | *S. cerevisiae* |
| *L. plantarum* | *L. pontis* | *A. penicillioides* |
| *L. brevis* | *L. panis* | *Al. tenuissima* |
| *L. paralimentarius* | *L. frumenti* | *X. bisporus* |
| *L. crustorum* | *L. reuteri* | *Al. dactytidicola* |
| *L. mindensis* | *L. delbrueckii* | *X. dermatitidis* |
| *L. nantensis* | *L. amylovorus* | *V. victoriae* |
| *Leuconostoc* spp. | *L. crispatus* | *A. montevidensis* |
| *Weissella* spp. | *L. acidophilus* | *Cl. delicatutum* |
| *P. pentosaceus* | *L. sanfranciscensis* | *Monilia* spp. |
| *Limosilactobacillus fermentum* | | |
| *Lacticaseibacillus casei* | | |

- *A. penicillioides* (*Aspergillus penicillioides*), *Al. tenuissima* (*Alternaria tenuissima*), *X. bisporus* (*Xeromyces bisporus*), *Al. dactytidicola* (*Alternaria dactytidicola*), *X. dermatitidis* (*Xerochrysium dermatitidis*), *V. victoriae* (*Vishniacozyma victoriae*), *A. montevidensis* (*Aspergillus montevidensis*), *Cl. delicatutum* (*Cladosporium delicatutum*)

## 4. Conclusion

SD has a rich historical, with various reports emphasizing its efficacy in improving the quality of bread and prolonging its shelf life. The microbiota of isolated traditional SD is primarily composed of heterofermentative species. Key members of this microbiota include *L. brevis, P. acidilactici*, and *L. plantarum*. The predominant yeasts found in this environment are *S. cerevisiae, Pichia kudriavzevii*, and *Kluyveromyces marxianus*. When fermentation occurs at temperatures above 30°C, the dominant microorganisms shift to homofermentative and facultative heterofermentative lactobacilli, such as *L. fermentum* and *L. plantarum*. In contrast, when temperatures drop below 30°C, the microbiota is dominated by heterofermentative lactobacilli, including *L. sanfranciscensis*.

***Table 2 Current scientific name and bases of some microorganisms in the text accepted at the National Center for Biotechnology Information (NCBI, 2025)***

| **Current scientific name** | **Basioynm** |
|---|---|
| *Lactiplantibacillus plantarum* | *Lactobacillus plantarum* |
| *Limosilactobacillus fermentum* | *Lactobacillus fermentum* |
| *Fructilactobacillus sanfranciscensis* | *Lactobacillus sanfranciscensis* |
| *Torulaspora delbrueckii* | *Saccharomyces delbrueckii* |
| *Meyerozyma guilliermondii* | *Pichia guilliermondii* |
| *Limosilactobacillus pontis* | *Lactobacillus pontis* |
| *Limosilactobacillus panis* | *Lactobacillus panis* |
| *Companilactobacillus paralimentarius* | *Lactobacillus paralimentarius* |
| *Companilactobacillus alimentarius* | *Lactobacillus alimentarius* |
| *Companilactobacillus crustorum* | *Lactobacillus crustorum* |
| *Companilactobacillus mindensis* | *Lactobacillus mindensis* |
| *Companilactobacillus nantensis* | *Lactobacillus nantensis* |
| *Limosilactobacillus frumenti* | *Lactobacillus frumenti* |
| *Limosilactobacillus reuteri* | *Lactobacillus reuteri* |
| *Lactobacillus crispatus* | *Eubacterium crispatum* |
| *Lactiplantibacillus paraplantarum* | *Lactobacillus paraplantarum* |
| *Lactiplantibacillus pentosus* | *Lactobacillus pentosus* |
| *Companilactobacillus paralimentarius* | *Lactobacillus paralimentarius* |
| *Leuconostoc mesenteroides* | *Ascococcus mesenteroides* |
| *Kluyveromyces marxianus* | *Saccharomyces marxianus* |
| *Wickerhamomyces anomalus* | *Saccharomyces anomalus* |
| *Lacticaseibacillus casei* | *Lactobacillus casei* |

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