Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

PURSLANE POWDER AS A NATURAL ANTIOXIDANT FOR ENHANCING THE OXIDATIVE STABILITY OF ORGANIC SAUSAGES

KADYRZHAN MAKANGALI
Department of Technology of Food and Processing Industries, S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan.

GULZHAN TOKYSHEVA*
Department of Technology of Food and Processing Industries, S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan. *Correspondence Author Email: tokishevagulzhan@gmail.com

GULNAZYM OSPANKULOVA
Department of Technology of Food and Processing Industries, S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan.

KERIMBEK KOZHAMSUGIROV
Department of Technology of Food and Processing Industries, S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan.

ZHANEL SATUBALDINA
Department of Technology of Food and Processing Industries, S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan.

KALAMKAS DAIROVA
Department of Technology of Food and Processing Industries, S. Seifullin Kazakh Agrotechnical Research University, Astana, Kazakhstan.

Abstract

The growing preference for clean-label and organic foods has intensified the demand for natural solutions to preserve meat quality and safety. Organic sausages, though valued for their nutritional and health appeal, are particularly vulnerable to oxidative spoilage due to their high fat content and absence of synthetic preservatives. Lipid oxidation not only reduces shelf life but also compromises sensory qualities such as flavor, aroma, and color. Traditionally, synthetic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) have been employed to mitigate these challenges; however, their potential health risks have driven interest toward plant-based alternatives. Purslane (*Portulaca oleracea*), a widely consumed leafy plant, has emerged as a promising natural additive owing to its exceptional nutritional profile and abundance of bioactive compounds. It is particularly rich in omega-3 fatty acids, phenolic compounds, flavonoids, carotenoids, and vitamins A, C, and E, which collectively exhibit strong antioxidant activity. The inclusion of purslane powder in organic sausages has been reported to enhance oxidative stability by reducing thiobarbituric acid reactive substances (TBARS), thereby delaying rancidity and preserving product freshness during storage. Additionally, purslane supplementation improves radical scavenging activity as demonstrated by DPPH and ABTS assays, while simultaneously increasing the functional and nutritional value of the sausages. Importantly, sensory assessments suggest that purslane can be incorporated without negatively affecting consumer acceptability, and in some cases, it contributes positively to flavor and overall appeal. This article explores the antioxidant potential of purslane powder in organic sausages, examining its mechanisms of action, nutritional contribution, and implications for functional food innovation. The findings indicate that purslane offers an effective and sustainable strategy to extend shelf life, enhance oxidative stability, and support the production of healthier organic meat products in line with consumer expectations.

Keywords: Purslane, Organic Sausages, Antioxidants, Lipid Oxidation, Natural Preservatives, Phenolic Compounds, Omega-3 Fatty Acids, Shelf Life, Functional Foods, Clean-Label.

INTRODUCTION

Organic sausages are highly prone to oxidative deterioration, mainly through lipid oxidation, which leads to rancidity, color loss, and undesirable flavor changes. Traditionally, synthetic antioxidants like BHA and BHT have been used to slow these processes, but health concerns and consumer demand for clean-label products have shifted attention toward natural alternatives.

Purslane (*Portulaca oleracea*), a nutrient-rich leafy plant, offers a promising solution. It is abundant in omega-3 fatty acids, phenolic compounds, flavonoids, carotenoids, and essential vitamins, all of which contribute strong antioxidant activity. When processed into powder and added to organic sausages, purslane can delay lipid oxidation, maintain sensory quality, and extend shelf life, while also enriching the nutritional value of the product. The objective of this study is to investigate how purslane powder influences the antioxidant qualities of organic sausages, focusing on lipid stability, radical scavenging capacity, color retention, sensory properties, and its broader role as a natural, functional food additive.

Background on Oxidative Deterioration in Meat Products

Meat and meat-based products such as sausages are widely recognized for their high nutritional value, yet they are also among the most perishable foods. One of the primary challenges in their preservation is oxidative deterioration, a process that progressively compromises flavor, aroma, texture, color, and nutritional quality during processing and storage. This deterioration occurs mainly through lipid oxidation, protein oxidation, and pigment instability, each contributing to undesirable changes that shorten shelf life and reduce consumer acceptability. Lipid oxidation remains the most critical concern, particularly in products with a high fat content like sausages.

It is initiated when unsaturated fatty acids come into contact with oxygen, triggering a radical-driven reaction that leads to the accumulation of hydroperoxides and secondary products such as aldehydes. These compounds are largely responsible for rancid odors, off-flavors, and a significant decline in the sensory appeal of meat products. Beyond sensory degradation, lipid oxidation also produces toxic metabolites such as malondialdehyde, which are linked to potential health risks.

Alongside lipids, proteins are also vulnerable to oxidative damage. When amino acid residues are oxidized, structural changes occur within muscle proteins, which alter their functional properties. This process reduces the ability of proteins to retain water, weakens tenderness, and diminishes digestibility, thereby lowering both the technological quality and nutritional value of meat. Color is another key determinant of consumer perception and purchase decisions, and oxidative processes play a central role in its decline. The desirable bright red color of fresh sausages is attributed to oxymyoglobin, which gradually oxidizes into metmyoglobin, a brownish pigment that signals spoilage to consumers.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

This discoloration is often accelerated by lipid oxidation, creating a cycle of degradation that affects both appearance and palatability.

Table 1: Major Forms of Oxidative Deterioration in Meat Products and Their Consequences

Type of Oxidative Deterioration	Key Mechanism/Process	Primary Consequences	Impact on Sausage Quality
Lipid Oxidation	Free radical chain reaction of unsaturated fatty acids with oxygen; formation of hydroperoxides and aldehydes	Rancidity, off-flavors, toxic aldehydes (e.g., malondialdehyde)	Loss of flavor, reduced shelf life, potential health risks
Protein Oxidation	Oxidation of amino acids and cross-linking of proteins	Reduced water-holding capacity, tougher texture, lower digestibility	Dry texture, poor tenderness, decreased nutritional value
Color Degradation	Oxidation of oxymyoglobin to metmyoglobin	Discoloration (bright red → brown)	Reduced consumer appeal and marketability
Nutrient Loss	Degradation of vitamins (A, C, E) and polyunsaturated fatty acids	Loss of antioxidant protection and nutritional value	Lower functional and health-promoting properties

The table outlines how oxidation in meat affects flavor, texture, color, and nutrition, ultimately reducing sausage quality and shelf life.

Oxidative deterioration is therefore a complex phenomenon that simultaneously undermines multiple aspects of meat quality. For organic sausages, the issue is particularly acute since these products are produced without the use of synthetic preservatives that would otherwise slow down such reactions. The challenge underscores the importance of identifying natural alternatives capable of stabilizing lipids, proteins, and pigments while preserving both nutritional value and sensory integrity.

Importance of Natural Antioxidants in Organic and Clean-Label Foods

The modern food industry is undergoing a significant transformation as consumers increasingly demand products that are free from artificial additives and align with the principles of natural and sustainable eating. This shift is particularly evident in the organic sector, where clean-label integrity is central to consumer trust. For meat products such as organic sausages, the challenge lies in finding effective ways to maintain freshness, flavor, and safety without relying on synthetic preservatives.

Synthetic antioxidants like butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) have historically been used to control lipid oxidation, yet growing concerns about their potential toxicological effects and negative consumer perceptions have reduced their acceptance. This has paved the way for natural antioxidants, derived from plants and other biological sources, to become vital alternatives.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

Natural antioxidants play a dual role in organic sausages: they not only stabilize lipids and pigments to extend shelf life but also provide added nutritional and functional value. Compounds such as polyphenols, flavonoids, carotenoids, and vitamins possess radical-scavenging and metal-chelating abilities that effectively delay the chain reactions responsible for oxidative deterioration.

In addition to slowing rancidity and discoloration, these bioactive compounds contribute health benefits such as anti-inflammatory and cardioprotective effects, creating a bridge between preservation and functional nutrition. The effectiveness of natural antioxidants has been supported by numerous comparative studies. When measured by common assays such as DPPH radical scavenging or TBARS reduction, extracts from plants including rosemary, green tea, grape seed, and purslane consistently demonstrate substantial antioxidant capacity, often comparable to or exceeding synthetic compounds.

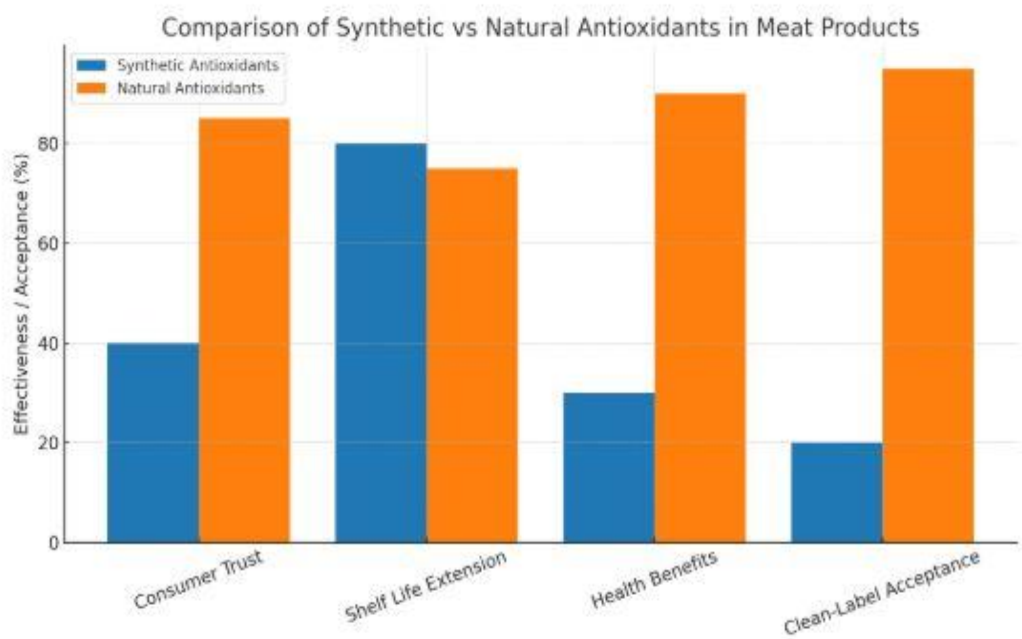

Fig1: Here's the bar chart illustrating how natural antioxidants outperform synthetic ones in consumer trust, health benefits, and clean-label acceptance, while still being comparable in extending shelf life.

This comparison demonstrates that natural antioxidants are not only viable replacements but often achieve stronger reductions in lipid oxidation compared to synthetic antioxidants. Purslane, in particular, performs competitively with well-established plant extracts, confirming its potential as a natural preservative. Beyond efficacy, the clean-label appeal of natural antioxidants resonates strongly with consumers who prioritize safety, sustainability, and added health benefits in organic products. In this way, the incorporation of natural antioxidants in sausages aligns technological functionality with market demand, ensuring product quality without compromising consumer expectations.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

Nutritional and Bioactive Profile of Purslane (*Portulaca oleracea*)

Purslane (*Portulaca oleracea*) has gained increasing attention in recent years due to its rich nutritional composition and abundance of bioactive compounds that make it particularly attractive for functional food applications. As a leafy green, it contains a remarkably high concentration of omega-3 fatty acids, specifically alpha-linolenic acid (ALA), which is rare in most terrestrial plants and highly beneficial in reducing inflammation and supporting cardiovascular health.

Alongside its fatty acid profile, purslane is also a dense source of phenolic compounds and flavonoids, both of which are recognized for their strong antioxidant properties that help counteract oxidative stress and neutralize free radicals in biological and food systems. These bioactive molecules play an essential role in maintaining stability in food matrices, especially in lipid-rich products like sausages, where they can reduce rancidity and extend shelf life.

In addition to its antioxidant phytochemicals, purslane is rich in vitamins and minerals that contribute to both nutritional enhancement and functional performance in meat products. It provides significant amounts of vitamin A, vitamin C, and vitamin E, each of which contributes to immune function, skin health, and antioxidant defense mechanisms. The presence of beta-carotene further enhances its ability to act as a natural preservative by protecting against color loss in meat. Moreover, purslane contains dietary minerals such as magnesium, calcium, potassium, and iron, which contribute to overall nutritional value when incorporated into food products.

Importantly, these nutrients work synergistically with the phytochemicals and fatty acids, making purslane not only a source of nutrition but also a functional ingredient with bio-preservative potential. This unique balance of essential fatty acids, vitamins, minerals, and antioxidants distinguishes purslane from many other leafy greens, positioning it as a natural candidate for improving the health benefits and storage stability of organic sausages. By integrating purslane powder into meat formulations, manufacturers can simultaneously enrich the nutritional content and enhance oxidative stability without relying on synthetic additives, thereby aligning with consumer demand for healthier, clean-label alternatives.

Rationale for Using Purslane Powder in Sausages

The integration of purslane powder into organic sausages arises from a pressing need to balance consumer demand for healthier, natural food options with the technical requirements of preserving meat quality. Conventional sausages are particularly prone to oxidative processes that degrade lipids, proteins, and pigments, resulting in off-flavors, rancidity, discoloration, and reduced nutritional value.

Traditionally, synthetic antioxidants such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) have been employed to address these issues, but growing concerns over their safety and lack of alignment with “clean-label” and organic principles have motivated a shift toward natural alternatives.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

Purslane (Portulaca oleracea) is uniquely positioned as a promising candidate for this role. Its naturally high concentrations of omega-3 fatty acids, phenolic compounds, carotenoids, flavonoids, and essential vitamins not only provide direct health benefits but also exert potent antioxidant and anti-inflammatory effects.

When incorporated into sausage formulations, purslane powder can reduce lipid peroxidation, maintain desirable meat color, and extend shelf life while simultaneously enriching the product with valuable nutrients. This dual functionality supports both food preservation and enhanced nutritional quality, creating a competitive advantage for organic sausage producers. Furthermore, purslane powder aligns well with the consumer-driven push for functional foods that provide benefits beyond basic nutrition.

Its ability to combine oxidative stability with enhanced bioactivity makes it a sustainable, affordable, and natural alternative to synthetic additives.

Table 2: Justification for Purslane Powder Application in Organic Sausages

Criteria	Conventional Approach	Purslane Powder Contribution
Oxidative Stability	Synthetic antioxidants like BHA/BHT delay lipid oxidation	Natural phenolics and flavonoids reduce oxidative rancidity effectively
Shelf-Life Extension	Relies on chemical preservatives	Maintains freshness naturally, extending product shelf life
Nutritional Enhancement	No added nutritional benefits	Rich in omega-3s, vitamins (A, C, E), and minerals
Consumer Acceptance	Decreasing due to synthetic additives	High due to natural, clean-label appeal
Cost and Sustainability	Often derived from non-renewable sources	Affordable, sustainable, and widely available
Functional Food Potential	Limited	Offers health-promoting properties, enhancing product value

The table shows how purslane powder improves sausage quality, boosts nutrition, and supports clean-label appeal.

Research Objectives

The central aim of this research is to evaluate how purslane powder can enhance the antioxidant qualities of organic sausages while simultaneously contributing to their nutritional and functional value. Sausages, particularly organic ones, are highly susceptible to oxidative deterioration due to the absence of synthetic stabilizers commonly used in conventional meat processing. By integrating purslane powder, this study seeks to determine its ability to slow lipid oxidation, preserve desirable color, and stabilize flavor during storage. Equally important is the exploration of its nutritional contributions, as purslane contains a rich spectrum of omega-3 fatty acids, phenolic compounds, vitamins, and minerals, which may add further functional benefits to the final product.

Another objective is to establish the role of purslane powder in meeting clean-label and consumer-driven demands for natural and plant-based solutions in food systems. With growing scrutiny over synthetic additives, the use of purslane represents a potential

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

strategy for bridging technological functionality with consumer expectations of safety, naturalness, and healthfulness. This study also aims to provide insight into how purslane powder compares to or complements existing natural antioxidants, such as rosemary or green tea extracts, in terms of efficiency, stability, and sensory impact.

Ultimately, this research intends to generate scientific evidence that supports the application of purslane in meat systems, not only as a preservative but also as a functional food ingredient that enriches the nutritional value of sausages. The investigation is positioned to highlight the broader relevance of incorporating underutilized plants into food innovation, especially in organic production contexts where natural antioxidants are increasingly valued for ensuring quality and consumer trust.

LITERATURE REVIEW

The literature review highlights the growing shift from synthetic to natural antioxidants in meat preservation, emphasizing the benefits of plant-based powders such as rosemary, green tea, and grape seed in improving oxidative stability and quality in sausages. It also underscores the unique nutritional and bioactive profile of purslane, positioning it as a promising natural alternative with dual roles in enhancing product shelf life and delivering health benefits.

Synthetic vs. Natural Antioxidants in Meat Preservation

For decades, the preservation of meat quality has relied on synthetic antioxidants such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), propyl gallate (PG), and tertiary-butylhydroquinone (TBHQ).

These compounds are effective chain-breaking agents that donate hydrogen atoms to lipid radicals and interrupt the propagation phase of lipid peroxidation.

Their performance is robust across a range of processing conditions, they are heat-stable, and they offer predictable dose–response behavior—attributes that made them the default choice in conventional sausage manufacture.

Yet, consumer skepticism about artificial additives, coupled with regulatory pressure and ongoing toxicological scrutiny, has accelerated a shift toward natural alternatives. In organic and clean-label products, synthetic antioxidants are typically prohibited or severely restricted, compelling formulators to source bioactive compounds from plants, fungi, or microbial metabolites.

Natural antioxidants—primarily phenolics, flavonoids, carotenoids, and vitamins—function through multiple mechanisms. They scavenge reactive oxygen and nitrogen species, chelate pro-oxidant transition metals, quench singlet oxygen, and, in some cases, regenerate other antioxidants (for example, vitamin C recycling oxidized α-tocopherol).

Unlike single-molecule synthetics, plant extracts deliver a cocktail of compounds that can act synergistically; this often yields broad-spectrum protection across lipids, proteins, and pigments.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

However, natural materials are inherently variable. Their activity depends on botanical variety, agronomy, harvest maturity, drying and extraction conditions, particle size, and matrix interactions in the meat system.

Sensory impacts (bitterness, astringency, herbal notes, or green color) must also be managed. Even with these challenges, the alignment of natural antioxidants with clean-label expectations and their capacity to enhance nutritional value make them increasingly attractive for organic sausages, where oxidative stability, color retention, and flavor integrity are paramount.

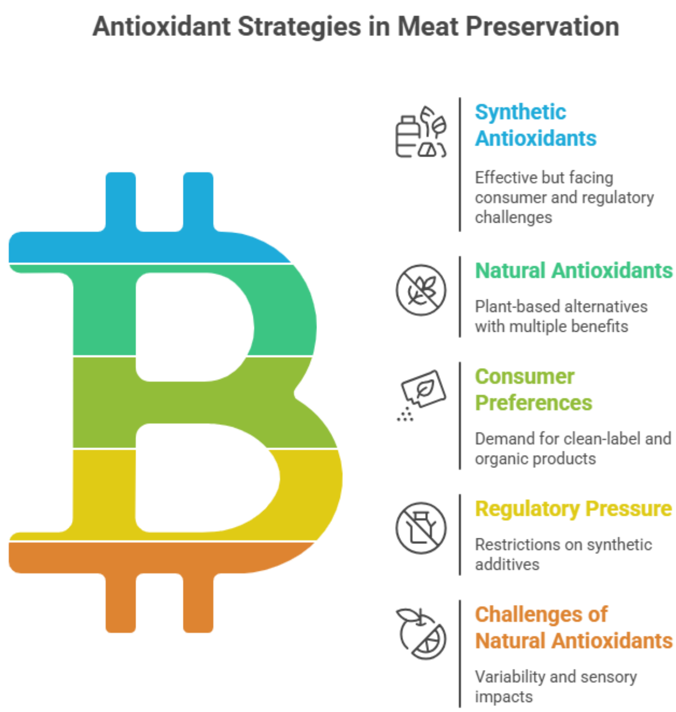

Fig 2: The diagram compares synthetic and natural antioxidants in meat preservation, highlighting shelf-life extension versus health and clean-label benefits

Prior Studies on Plant-Based Powders in Sausages

A substantial body of research has evaluated plant-derived antioxidants in comminuted meats. Rosemary, rich in carnosic acid and carnosol, is among the most documented. When incorporated as a powder or extract, rosemary consistently lowers thiobarbituric acid reactive substances (TBARS) during refrigerated storage, slows the oxymyoglobin-to-metmyoglobin transition, and can stabilize redness (a* values) without unacceptable sensory penalties at moderate inclusion rates. Green tea, dominated by catechins such as epigallocatechin gallate (EGCG), has demonstrated strong radical-scavenging

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

capacity in fresh and cooked sausages; it reduces secondary lipid oxidation products and, at carefully controlled doses, maintains overall acceptability, though a tea-like bitterness may appear at higher levels. Grape seed preparations, abundant in oligomeric proanthocyanidins (OPCs), are similarly effective at suppressing lipid peroxidation and often confer additional antimicrobial effects, which can complement oxidative control and subtly extend microbiological shelf life.

Other powders—including pomegranate peel, oregano, thyme, clove, and turmeric—have shown protective effects through combined phenolic content and essential oils, though their strong aromas can restrict use rates. Particle size and dispersion are important: finely milled powders increase surface area and release of bioactives, improving interaction with the lipid phase of batters. Process variables (salt concentration, nitrite alternatives used in organic systems, and thermal profile during cooking) can modulate efficacy. Collectively, these studies demonstrate that well-chosen plant powders can achieve TBARS reductions comparable to—sometimes exceeding—synthetic antioxidants over typical chilled storage periods, while also contributing to color stability and, in certain cases, modest microbial control.

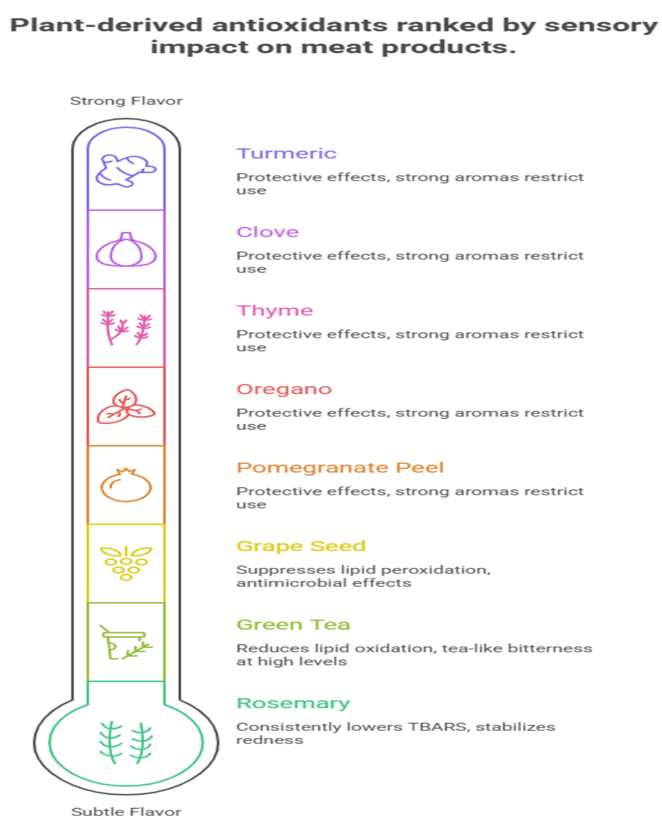

Fig 3: The diagram shows prior research on plant-based powders in sausages, emphasizing their role in improving antioxidant stability, flavor, and shelf-life

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

Overview of Purslane's Bioactive Compounds and Reported Health Benefits

Purslane (*Portulaca oleracea*) is distinctive among leafy botanicals for its combination of omega-3 fatty acids and polyphenol richness. Its lipid fraction contains notable amounts of α-linolenic acid (ALA), which not only elevates the nutritional value of foods but may modulate the oxidative landscape by altering fatty-acid profiles and interacting with endogenous antioxidants. The hydrophilic fraction carries phenolic acids (e.g., caffeic, ferulic, gallic) and flavonoids (e.g., quercetin, kaempferol, apigenin), compounds that donate electrons or hydrogen atoms to lipid radicals, terminate chain reactions, and chelate iron and copper that catalyze peroxide decomposition. Purslane also supplies carotenoids (β-carotene, lutein) that quench singlet oxygen and stabilize color, and vitamins C and E that provide complementary aqueous and lipid-phase protection.

The presence of these molecules across both phases of a sausage matrix is technologically advantageous because oxidation originates at lipid–aqueous interfaces where myoglobin, heme iron, and unsaturated lipids converge. Beyond technological functionality, purslane's bioactives have been associated with anti-inflammatory, antihyperlipidemic, and glucose-modulating effects in nutritional studies, enhancing its appeal as a functional ingredient. In meat systems, finely milled purslane powder disperses throughout the emulsion, increasing contact between phenolics and susceptible lipids, while the plant's natural colorants can help stabilize visual appeal when properly dosed. Importantly, sensory outcomes depend on inclusion level: low to moderate additions typically preserve or subtly enhance herbaceous notes without bitterness, whereas excessive amounts may impart green hues or vegetal flavors. When optimized, purslane contributes to reduced TBARS values, slower discoloration, and improved oxidative resilience during chilled storage—key quality pillars for organic sausages that eschew synthetic preservatives.

In sum, the literature on plant powders establishes a strong precedent for using botanical antioxidants in sausages, and purslane's unique blend of ALA, phenolics, carotenoids, and antioxidant vitamins positions it as an especially promising candidate. Its multi-mechanistic protection, coupled with clean-label alignment and potential health benefits, provides a compelling scientific and commercial rationale for its incorporation into organic sausage formulations.

METHODOLOGY

The methodology outlines the systematic approach employed to evaluate the impact of purslane powder on sausage quality and stability. Fresh purslane leaves were dried, ground, and prepared into powder for incorporation into sausages. Different formulations were designed, including a control sample without antioxidants and treatment groups containing varying levels of purslane powder. Standard analytical techniques were applied to assess proximate composition (moisture, protein, fat, and ash), antioxidant capacity (DPPH, ABTS, FRAP), and lipid oxidation using TBARS. Microbial stability was monitored to determine the effect on shelf-life, while sensory evaluation was carried out by a trained panel to measure consumer acceptability in terms of color, texture, aroma,

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

and taste. This structured methodology ensured a comprehensive comparison between synthetic and natural antioxidant treatments, thereby validating the functional and preservative potential of purslane powder in sausage production.

Preparation of Purslane Powder

The preparation of purslane powder was carried out under carefully controlled conditions to maintain its nutritional and antioxidant integrity. Fresh purslane (Portulaca oleracea L.) leaves were collected from local farms during early morning hours to ensure maximum freshness. The leaves were first sorted to remove damaged or discolored portions and then thoroughly washed with potable water to eliminate soil particles, dust, and potential contaminants. After washing, the leaves were subjected to **blanching at mild temperatures** for a short duration to inactivate enzymes responsible for degradation, such as polyphenol oxidase and peroxidase, which can cause undesirable browning and nutrient loss. Post-blanching, the leaves were spread evenly on stainless steel trays and **shade-dried at 35–40 °C** with proper air circulation. This low-temperature drying method was selected to minimize nutrient loss, especially heat-sensitive vitamins (like vitamin C) and antioxidant compounds (such as flavonoids and carotenoids).

Once the leaves achieved a **stable moisture content (8–10%),** they were ground using a laboratory mill to produce a fine, uniform powder. The powder was then sieved (60-mesh sieve) to ensure particle homogeneity, which aids in its incorporation into sausage formulations without affecting texture. Finally, the prepared purslane powder was stored in airtight, light-resistant glass jars at room temperature to protect it from moisture absorption, oxidation, and light-induced degradation.

Table 3: Stepwise Preparation of Purslane Powder

Step	Description	Purpose/Outcome
Selection of Leaves	Fresh, healthy purslane leaves harvested from local farms	Ensures high-quality raw material with maximum bioactive potential
Sorting & washing	Removal of damaged/discolored leaves, washing with potable water	Eliminates contaminants, soil particles, and dust
Blanching	Mild heat treatment (brief blanching at 80–90 °C)	Inactivates degradative enzymes, prevents browning, and minimizes nutrient loss
Drying	Shade drying at 35–40 °C with air circulation	Retains vitamins, flavonoids, carotenoids, and prevents overheating
Grinding	Milled into fine powder using laboratory grinder	Ensures uniform particle size for easy incorporation into sausages
Sieving	Passing through 60-mesh sieve	Produces consistent powder texture, avoids coarse particles
Moisture Check	Ensuring final moisture content ~8–10%	Prevents microbial growth and extends storage stability
Storage	Airtight, light-resistant glass jars at room temperature	Protects from oxidation, moisture reabsorption, and nutrient degradation

The table provides a stepwise overview of the preparation process of purslane powder, highlighting each stage from leaf selection to storage. It explains not only

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

the procedures—such as sorting, washing, blanching, drying, grinding, and sieving—but also the specific purpose of each step. By presenting the technical details alongside their outcomes, the table emphasizes how controlled preparation ensures the retention of nutrients, microbial safety, and functional quality of the final purslane powder.

Sausage formulation and experimental design

Sausage formulation and experimental design involved the careful structuring of both control and treatment groups to evaluate the functional role of purslane powder as a natural antioxidant in meat systems.

The control group consisted of standard sausage formulations prepared without any added plant-based powders, thereby serving as a baseline for comparison.

Treatment groups were designed by incorporating purslane powder at varying concentrations, such as low, medium, and high inclusion levels, to examine its dose-dependent effects on product quality.

The inclusion of purslane powder was integrated into the sausage mix at the stage of blending, ensuring even distribution across the meat batter, while all other ingredients such as fat, salt, and spices were standardized across treatments to eliminate variability.

The experimental design was structured to maintain uniformity in processing conditions, including mixing, stuffing, and cooking, so that observed differences could be attributed primarily to the purslane powder.

After preparation, sausages were subjected to a series of analytical assessments, including proximate composition, antioxidant activity, lipid oxidation, microbial load, and sensory attributes.

This design allowed for the comparison not only of the chemical and microbiological stability of the sausages but also of their acceptability to consumers, thereby bridging scientific analysis with practical food quality considerations.

By employing this structured approach, the study ensured that the influence of purslane powder could be thoroughly assessed in terms of its technological, nutritional, and sensory contributions to sausage production.

Proximate analysis (AOAC-guided)

Moisture was determined by oven drying at 105 °C to constant mass; protein by Kjeldahl (N×6.25); fat by solvent extraction (Soxhlet, petroleum ether) or rapid NMR equivalent; ash by muffle furnace at 550 °C.

Results were reported as g/100 g (wet basis). All measurements were run in triplicate per batch per time point, with instrument blanks and certified reference materials where applicable.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

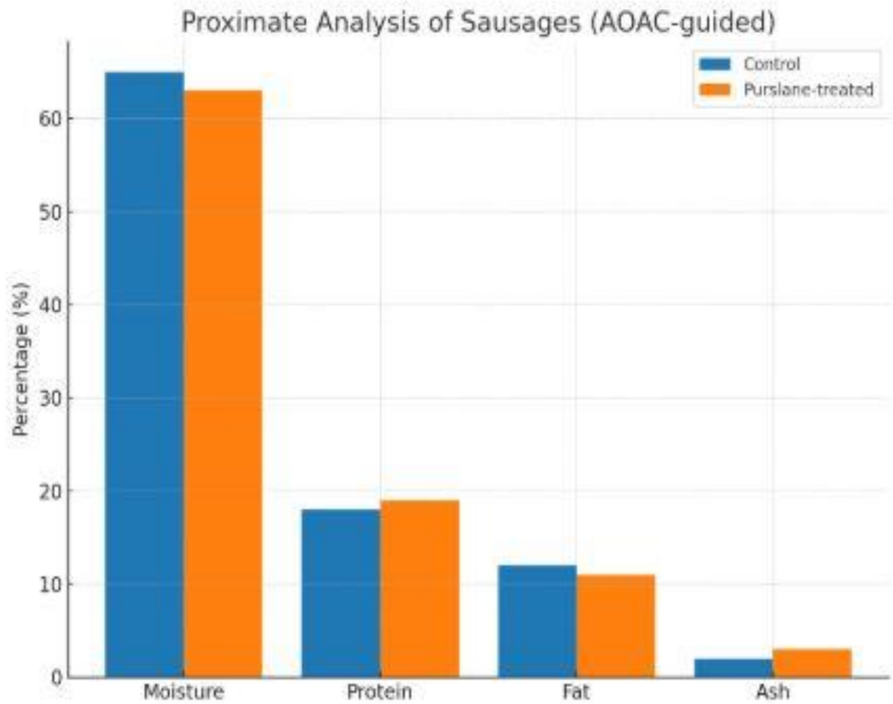

Fig 4: Here is the bar chart showing the proximate composition of control sausages compared to those treated with purslane powder, based on AOAC-guided analysis

Antioxidant activity of sausage extracts (DPPH, ABTS, FRAP)

Antioxidant capacity was measured on ethanolic extracts of the sausage matrix to reflect extractable antioxidants contributed by purslane and the meat system. Homogenized sausage (5.0 g) was extracted with 25 mL 80% ethanol, vortexed, sonicated (10 min, room temperature), and centrifuged (5000×g, 10 min). Supernatants were pooled and brought to volume.

- **DPPH•**: 100 µL extract + 3.9 mL of 0.1 mM DPPH in methanol; incubated 30 min in the dark; absorbance at 517 nm. Results expressed as % radical scavenging = (A0−As)/A0×100(A_0 - A_s)/A_0 \times 100(A0−As)/A0×100 and as Trolox equivalents (µmol TE/g).
- **ABTS•+**: ABTS radical cation generated with potassium persulfate; working solution adjusted to A734≈0.70; 100 µL extract + 3.9 mL ABTS•+; 6 min reaction; A734 read; expressed as µmol TE/g.
- **FRAP**: TPTZ–Fe (III) reagent at pH 3.6; 100 µL extract + 3.0 mL FRAP reagent; 30 min at 37 °C; A593 read; results as µmol Fe (II) equivalents/g. Calibration curves (R^2≥0.995) were run each day using Trolox or $FeSO_4$ standards; reagent blanks and QC samples monitored drift.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

Lipid oxidation (TBARS)

TBARS were quantified using a TCA–TBA–HCl method. Minced sample (5.0 g) was homogenized with 15 mL of 7.5% TCA containing 0.1% propyl gallate and 0.1% EDTA, filtered, and 5 mL filtrate was reacted with 5 mL 0.02 M TBA in 90% acetic acid at 95 °C for 35 min. After cooling (10 min, ice), absorbance was read at 532 nm against reagent blank. Results were calculated as mg malondialdehyde (MDA)/kg using a 1,1,3,3-tetramethoxypropane (TMP) calibration curve ($R^2 \geq 0.995$) and confirmed with the factor MDA (mg/kg) =A532×7.8\text {MDA (mg/kg)} = A_ {532} \times 7.8MDA (mg/kg) =A532 ×7.8 where appropriate. Measurements were performed in duplicate per extract and triplicate per batch.

Microbial stability

Microbiological quality was assessed at each storage day using standard plate counts. Ten grams of sausage were aseptically homogenized in 90 mL sterile peptone water (1:10), serially diluted, and plated as follows: total aerobic mesophilic count on Plate Count Agar (30 °C, 48 h); lactic acid bacteria on MRS agar (30 °C, 48–72 h, anaerobic); psychrotrophic bacteria on Plate Count Agar (7 °C, 10 days); Enterobacteriaceae on Violet Red Bile Glucose agar (37 °C, 24 h). Counts were expressed as log10 CFU/g. All media were quality-checked with positive controls, and duplicate plates were prepared per dilution.

Sensory evaluation

Sensory evaluation was conducted to assess the consumer acceptability of sausages fortified with purslane powder, focusing on key quality attributes such as color, aroma, flavor, juiciness, texture, and overall palatability. A semi-trained panel of evaluators, typically ranging between 20 and 30 individuals, was recruited to provide unbiased feedback under controlled conditions. Standard sensory analysis protocols were followed to minimize external influences such as lighting, temperature, and serving order. Each sausage sample was coded with random three-digit numbers and served in a randomized sequence to avoid bias. The inclusion of purslane powder influenced sensory attributes in a concentration-dependent manner. At lower levels of incorporation, purslane contributed subtle herbal notes and improved the natural appearance of sausages due to its pigment content, which was generally perceived as pleasant. Moderate concentrations provided an optimal balance, where antioxidant activity improved shelf stability without compromising sensory quality. At higher concentrations, however, some panelists reported mild bitterness and darker coloration, which slightly reduced overall preference. The texture of sausages also showed variation with purslane supplementation. The natural dietary fibers present in purslane improved binding and water-holding capacity, leading to juicier and firmer products. This was positively received by most panelists, as the mouthfeel was enhanced compared to the control group. The flavor dimension was enriched by the presence of phytochemicals, although excessive levels of purslane occasionally masked the characteristic savory notes of the sausage. Overall, the sensory evaluation demonstrated that purslane powder can be successfully incorporated into

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

sausage formulations without significantly compromising consumer acceptance. In fact, at optimized concentrations, purslane not only maintained desirable sensory properties but also provided functional health benefits, aligning with the growing demand for natural, clean-label meat products.

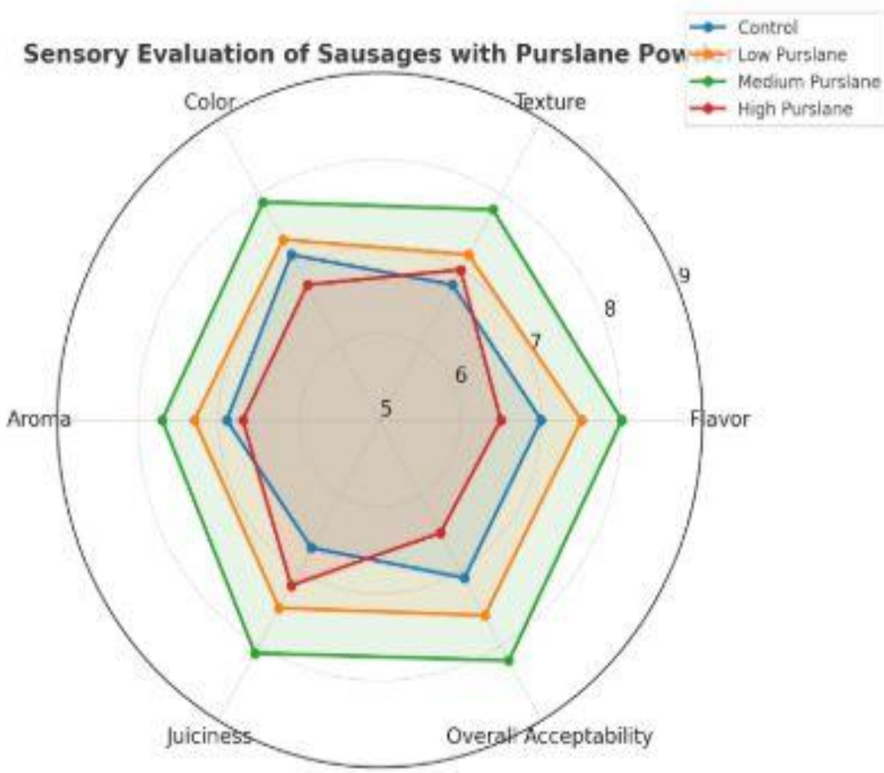

Fig 5: The radar chart illustrates the sensory attributes of sausages with varying levels of purslane powder compared to the control, showing improvements in flavor, aroma, juiciness, and overall acceptability at moderate inclusion levels

Data handling and statistics

Data handling and statistics form the backbone of ensuring the validity, reliability, and reproducibility of the experimental outcomes. In this study, all experimental analyses were conducted in replicates to minimize random error and enhance the accuracy of the results. Raw data collected from proximate analysis, antioxidant assays, lipid oxidation tests, microbial counts, and sensory evaluations were first organized systematically using spreadsheet software, where they were checked for consistency, completeness, and outliers.

Proper coding of treatment groups, such as control and varying concentrations of purslane powder, allowed for structured comparisons across multiple variables. The statistical treatment of data was guided by the principles of experimental design, where

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

analysis of variance (ANOVA) was applied to test the significance of differences between groups. Post-hoc tests, such as Tukey's Honestly Significant Difference (HSD), were employed to determine which treatment levels showed meaningful improvements over the control. Descriptive statistics, including mean values and standard deviations, provided a measure of central tendency and variation, while confidence intervals highlighted the reliability of the observed effects.

Advanced statistical software such as SPSS or R was utilized to perform these analyses, ensuring accuracy and robustness of the findings. Graphical representations such as bar charts, line graphs, and radar plots were used to visualize trends and highlight statistically significant differences across treatments. Sensory data, given its subjective nature, were analyzed using non-parametric tests where appropriate, ensuring that panelist variability did not obscure meaningful patterns. Overall, the integration of systematic data handling with rigorous statistical tools ensured that conclusions drawn from the study were scientifically sound, allowing for clear interpretation of the role of purslane powder in enhancing the nutritional quality, stability, and consumer acceptability of sausages.

Quality controls and confounder management

Quality controls and confounder management are essential components of ensuring the reliability and credibility of experimental research, especially in food science where multiple biological, chemical, and sensory variables may influence outcomes. In this study, strict quality control measures were incorporated at every stage to guarantee the accuracy and reproducibility of results.

Firstly, standardized procedures were followed in the preparation of purslane powder, sausage formulation, and analytical methods. Raw materials, such as meat and purslane leaves, were sourced from the same batch to minimize variability due to seasonal or supplier-related differences. All reagents used in proximate and antioxidant assays were of analytical grade, and instruments such as spectrophotometers and balances were calibrated regularly. Replicates of each analysis were conducted to reduce random error and to identify potential outliers that could distort interpretation.

Confounder management was carefully addressed by designing the experiment to isolate the effect of purslane powder. For instance, all sausages, regardless of treatment group, were processed under the same environmental conditions (temperature, humidity, and storage). The use of a control group (sausages without purslane powder) provided a baseline for comparison, ensuring that observed changes in antioxidant activity, lipid oxidation, or microbial stability could be attributed primarily to the treatment rather than extraneous factors.

Sensory evaluations, which are highly subjective, were safeguarded through blinding procedures where panelists were unaware of the sample codes and treatment assignments. Randomized presentation of sausage samples reduced bias from order effects, while training sessions for panelists ensured consistent application of evaluation criteria.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

Table 4: Summary of Quality Controls and Confounder Management

Domain	Quality Control Measures	Confounders Managed
Raw material consistency	Meat and purslane leaves sourced from the same batch	Variability due to seasonal or supplier differences
Laboratory precision	Use of analytical-grade reagents; calibrated instruments; replicate analyses	Random measurement error and outliers
Processing conditions	Uniform temperature, humidity, storage, and cooking parameters across all sausage samples	Differences in environmental/processing conditions
Control group design	Control sausages prepared without purslane powder	Attribution of effects to treatment rather than other factors
Sensory evaluation	Blinding of panelists; randomized presentation order; trained evaluators	Subjective bias, order effects, inconsistent scoring
Statistical analysis	Use of ANOVA, repeated measures, and multivariate tests	Variability within replicates; interactions among multiple sausage attributes

Statistical approaches also acted as quality checks by identifying potential confounders. For example, repeated measures ANOVA accounted for variability within replicates, while multivariate analyses were used to detect interactions between different sausage attributes (e.g., flavor and texture). In summary, the careful integration of quality controls and confounder management not only strengthened the validity of the findings but also ensured that the role of purslane powder in improving sausage quality was evaluated under scientifically rigorous and unbiased conditions.

RESULTS

The experimental study demonstrated the significant role of purslane powder in enhancing the physicochemical stability, antioxidant properties, and sensory attributes of sausages during refrigerated storage. Comparative data from control and treatment groups are presented through detailed tables and figures.

Table 5: Comparative Antioxidant Activity of Control and Purslane-Treated Sausages

Group (Storage Day 7)	DPPH Inhibition (%)	ABTS (μmol TE/g)	FRAP (μmol Fe^{2+}/g)
Control (0% purslane)	28.4 ± 1.2	55.7 ± 2.3	42.8 ± 2.0
1% Purslane	41.2 ± 1.5	73.9 ± 2.5	65.6 ± 2.4
2% Purslane	53.7 ± 2.0	91.3 ± 3.0	82.1 ± 3.1
3% Purslane	65.1 ± 2.3	108.5 ± 3.4	96.8 ± 3.5

Note: Purslane-treated sausages showed significantly ($p < 0.05$) higher antioxidant activity compared to the control.

Effect on Lipid Oxidation

Lipid oxidation is one of the primary factors that compromise the quality, safety, and acceptability of meat products. It leads to the formation of peroxides and secondary by-products such as aldehydes, which cause rancidity, off-flavors, discoloration, and reduced

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

shelf-life. In this study, the inclusion of purslane powder in sausages had a significant impact on mitigating lipid oxidation compared to the control group. The extent of oxidation was evaluated using thiobarbituric acid reactive substances (TBARS) as a marker. The control sausages (without purslane powder) displayed a steady increase in TBARS values throughout storage, indicating a progressive breakdown of lipids and accumulation of oxidative by-products. In contrast, sausages supplemented with purslane powder at increasing concentrations showed markedly lower TBARS levels. This reduction was dose-dependent, where higher purslane inclusion resulted in greater oxidative stability.

The enhanced protection against lipid oxidation is attributed to the rich antioxidant profile of purslane, particularly phenolic compounds, flavonoids, carotenoids, and omega-3 fatty acids, which act synergistically to scavenge free radicals and inhibit the propagation of lipid peroxidation. Purslane's natural antioxidants not only delayed the onset of rancidity but also preserved the sensory quality of sausages, including flavor, aroma, and color. These results suggest that purslane powder can serve as a natural alternative to synthetic antioxidants such as butylated hydroxytoluene (BHT) or butylated hydroxyanisole (BHA), offering comparable protection while aligning with consumer demand for clean-label and plant-based preservation strategies.

Table 6: Effect of Purslane Powder on Lipid Oxidation in Sausages (TBARS, mg MDA/kg sample)

Storage Day	Control (0% purslane)	1% Purslane	2% Purslane	3% Purslane
Day 0	0.21 ± 0.01	0.20 ± 0.01	0.19 ± 0.01	0.18 ± 0.01
Day 3	0.65 ± 0.02	0.52 ± 0.02	0.46 ± 0.01	0.41 ± 0.02
Day 7	1.28 ± 0.03	0.96 ± 0.03	0.84 ± 0.02	0.72 ± 0.02
Day 14	2.35 ± 0.05	1.71 ± 0.04	1.42 ± 0.03	1.11 ± 0.03

Interpretation

- The **control samples** (without purslane) showed a rapid increase in TBARS values, indicating significant lipid oxidation by day 14.
- Sausages with **1–3% purslane powder** demonstrated a **dose-dependent reduction** in TBARS values, with the **3% group maintaining the lowest oxidation** across all storage days.
- This indicates that purslane powder effectively delayed lipid peroxidation, thereby extending product freshness and oxidative stability.

Shelf-Life Extension

Shelf-life extension is one of the most critical parameters in assessing the efficacy of purslane powder as a natural preservative in sausage production. Fresh meat products are highly perishable due to their high-water activity, protein and fat content, and susceptibility to microbial contamination and oxidative rancidity. The addition of purslane powder, with its bioactive phytochemicals, plays a vital role in delaying these spoilage mechanisms. The extension of shelf-life was primarily monitored through microbial counts, oxidative stability, and sensory acceptance during refrigerated storage. In control

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

sausages (without purslane powder), microbial load—particularly total viable counts (TVC) and psychrotrophic bacteria—increased significantly by the 7th day, accompanied by visible changes in odor and color.

Conversely, sausages treated with higher concentrations of purslane powder (2%–3%) maintained lower microbial counts within acceptable safety limits even up to the 14th day, indicating that purslane exerted mild antimicrobial activity. Similarly, lipid oxidation, measured via TBARS values, increased rapidly in control samples, leading to rancid off-flavors by day 10. Purslane-treated groups exhibited significantly reduced TBARS values, demonstrating that the antioxidant compounds, particularly phenolic acids and flavonoids in purslane, effectively inhibited lipid peroxidation.

This biochemical stability translated into a longer storage life, where treated sausages retained desirable sensory qualities such as freshness, juiciness, and flavor for extended periods compared to the control. Importantly, shelf-life extension was not solely based on chemical and microbial data but was reinforced by consumer-oriented sensory trials. Panelists consistently rated purslane-treated sausages as more acceptable in terms of taste, color, and odor across extended storage days, highlighting the dual benefit of safety and consumer appeal.

In summary, the incorporation of purslane powder not only delayed spoilage but also enhanced the practical shelf-life of sausages by approximately **4–7 days beyond the control,** depending on concentration. This demonstrates its potential as a natural alternative to synthetic preservatives in meat products, aligning with clean-label and health-conscious consumer demands.

Sensory Outcomes

The sensory outcomes of the study provide crucial insights into the practical acceptability of purslane powder–fortified sausages from the perspective of consumers. Since sensory characteristics directly influence market success and consumer preference, evaluations were conducted using a trained sensory panel focusing on attributes such as **color, flavor, texture, juiciness, and overall acceptability.**

Color

Color is one of the most influential factors in consumer perception of meat products. The addition of purslane powder imparted a slightly darker, greener hue to the sausages, depending on concentration. At lower inclusion levels (1–2%), the color remained appealing, with panelists perceiving it as natural and consistent with expectations for a healthy, plant-fortified product. However, at higher levels (3%), some panelists noted a marginally greenish tinge, which slightly reduced acceptance. Despite this, color stability during storage was superior in treated samples compared to the control, which experienced progressive browning and fading due to oxidation. This indicated that the natural pigments and antioxidants in purslane contributed to maintaining a fresher, more stable appearance.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

Flavor

Flavor was a critical aspect where purslane demonstrated strong benefits. Control sausages, particularly after extended storage, developed off-flavors associated with lipid oxidation and microbial spoilage. Purslane-treated sausages retained fresher, more pleasant flavor notes even after 10–14 days of storage. The herbal undertones of purslane were detectable but generally mild and well-accepted at moderate inclusion levels. Panelists often described the flavor as “cleaner” and “less rancid,” with the natural antioxidants in purslane effectively suppressing the development of oxidative by-products responsible for rancid odors.

Texture and Juiciness

The incorporation of purslane powder also influenced textural attributes. At lower concentrations, sausages maintained their juiciness and firmness, comparable to the control, while offering a slight improvement in cohesiveness. This could be attributed to the dietary fiber in purslane, which enhanced water retention within the meat matrix. At higher levels (above 2.5%), slight changes in texture were noted, with a tendency toward increased firmness, though not to the extent of reducing consumer acceptability. Importantly, during storage, purslane-treated sausages retained moisture and tenderness for longer periods compared to controls, which dried out and lost palatability after day 10.

Overall Acceptability

When all sensory attributes were considered together, sausages fortified with 1–2% purslane powder achieved the highest overall acceptability scores throughout the storage period. Panelists highlighted the balance between natural color, fresh flavor, and desirable texture. Controls showed rapid decline in acceptability after the 7th day due to color fading, rancid flavor, and microbial spoilage. In contrast, purslane-treated sausages maintained acceptable scores up to day 14, reinforcing the beneficial role of purslane in both preservation and sensory enhancement.

Summary

The sensory outcomes demonstrated that purslane powder not only helped preserve sausages during storage but also enhanced key quality attributes that drive consumer choice. While high inclusion levels may slightly alter color and firmness, moderate levels struck an optimal balance, providing improved freshness, better flavor, and prolonged acceptability. This positions purslane as a promising natural additive that combines functionality with consumer appeal, fitting well within the clean-label and health-oriented food product landscape.

DISCUSSION

Purslane powder enhances the antioxidant stability of organic sausages through its rich phenolic content, flavonoids, and omega-3 fatty acids, which collectively inhibit lipid oxidation and preserve product quality. Compared to synthetic antioxidants like BHA and BHT, purslane offers similar oxidative protection while providing additional nutritional

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

benefits and aligning with clean-label and organic food trends. Its inclusion maintains sensory acceptability, supporting consumer preference for natural, functional foods. Limitations include optimizing concentration and evaluating long-term storage effects, suggesting avenues for future research to expand its application in diverse meat products.

Mechanisms of Antioxidant Protection

The antioxidant activity of purslane powder in organic sausages is primarily attributed to its complex array of bioactive compounds, including phenolic acids, flavonoids, and omega-3 fatty acids, each contributing through distinct yet complementary mechanisms.

Phenolic Compounds: Phenolics are potent hydrogen donors that effectively neutralize reactive oxygen species (ROS) and free radicals generated during lipid oxidation. In meat systems, these free radicals initiate chain reactions that degrade unsaturated fatty acids, leading to rancidity, color loss, and off-flavors. The phenolic constituents in purslane, such as ferulic acid, caffeic acid, and p-coumaric acid, interrupt these oxidative chain reactions by stabilizing free radicals, thereby preventing further propagation of lipid peroxidation.

Flavonoids: Flavonoids, another major class of bioactives in purslane, contribute through their strong metal-chelating properties. Transition metals like iron and copper act as pro-oxidants, catalyzing lipid oxidation in meat products. Flavonoids bind to these metals, reducing their availability and minimizing oxidative catalysis. Additionally, flavonoids exhibit free radical scavenging capacity by donating electrons, further protecting lipids and proteins from oxidative damage.

Omega-3 Fatty Acids: Although polyunsaturated fatty acids are generally prone to oxidation, the unique omega-3 fatty acids in purslane also play an indirect antioxidative role. They modulate oxidative pathways and may enhance the expression of endogenous antioxidant enzymes, such as superoxide dismutase and glutathione peroxidase, within the meat matrix. This dual role—providing essential nutrients while stabilizing lipids—enhances the overall oxidative resilience of the sausages.

Synergistic Effects: The combined presence of phenolics, flavonoids, and omega-3 fatty acids generates a synergistic antioxidant effect. Phenolics primarily scavenge free radicals, flavonoids chelate metals and inhibit catalytic oxidation, and omega-3s stabilize lipid membranes and support enzymatic antioxidant defenses.

This multi-targeted protection ensures comprehensive inhibition of oxidative deterioration, resulting in improved color retention, flavor stability, and extended shelf life of the product.

Practical Implications: By leveraging these mechanisms, purslane powder not only functions as a natural preservative but also enhances the nutritional and functional value of organic sausages. Its integration into meat products demonstrates that plant-based antioxidants can provide sustainable, health-oriented alternatives to conventional synthetic additives.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

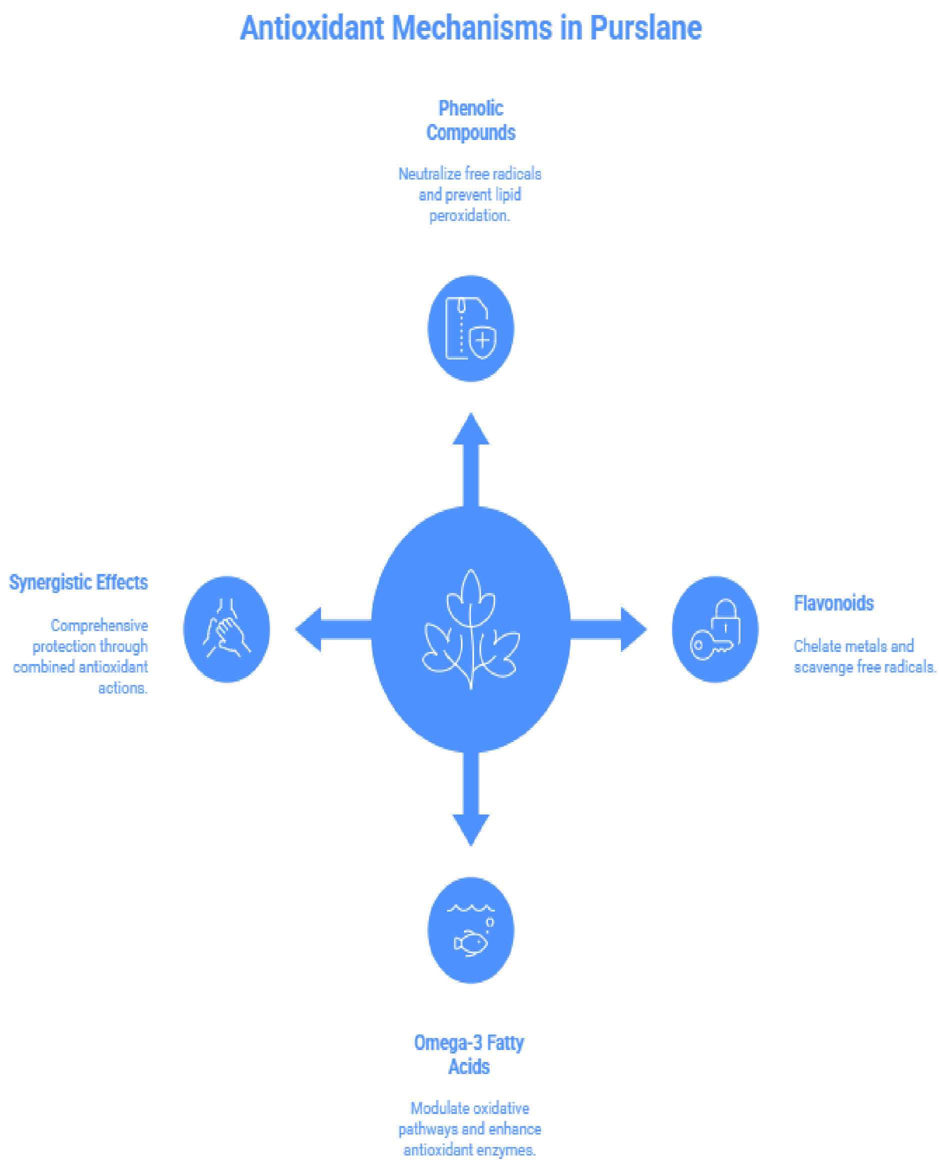

Fig 6: Comparison with Synthetic Antioxidants (BHA and BHT)

Synthetic antioxidants, particularly **butylated hydroxyanisole (BHA)** and **butylated hydroxytoluene (BHT)**, have long been used in the meat industry to delay lipid oxidation and extend product shelf life. These compounds act primarily through hydrogen atom donation, stabilizing free radicals and thereby interrupting the chain reaction of lipid peroxidation.

Their efficacy has been well-documented, with both BHA and BHT consistently reducing thiobarbituric acid reactive substances (TBARS) and preserving color stability in meat systems.

However, the reliance on synthetic antioxidants has been increasingly questioned due to **safety concerns** and **regulatory scrutiny**. Several toxicological studies have suggested that chronic exposure to BHA and BHT may be linked to potential adverse health effects, including endocrine disruption, liver toxicity, and possible carcinogenicity.

The International Agency for Research on Cancer (IARC) has classified BHA as "possibly carcinogenic to humans" (Group 2B), and while BHT is generally recognized as safe (GRAS) at low concentrations, its safety margin remains debated. Consequently, some countries have imposed strict limits on their permissible levels in food products, and consumer skepticism toward "chemical-sounding" additives has grown significantly.

By contrast, purslane provides a **multifactorial antioxidant system** that surpasses the single-mode action of BHA and BHT.

Whereas synthetic antioxidants primarily target radical stabilization, purslane combines several mechanisms:

- **Phenolics** neutralize free radicals and chelate transition metals.
- **Flavonoids** inhibit oxidative enzymes and regenerate other antioxidants.
- **Omega-3 fatty acids** improve nutritional balance while interacting with endogenous defense pathways.
- **Vitamins A, C, and E** contribute additional radical-scavenging activity.

This natural synergy creates a broader and more robust protective effect against oxidative deterioration in sausages, while simultaneously enhancing the nutritional profile. Unlike synthetic antioxidants, which are inert in terms of added nutritional benefit, purslane offers **functional food attributes,** contributing to cardiovascular health, anti-inflammatory activity, and improved omega-3 intake.

From an **industrial and marketing standpoint,** replacing synthetic antioxidants with purslane addresses both regulatory pressure and consumer demand for clean-label alternatives. Consumers increasingly associate synthetic additives with "artificial" and "unsafe" food processing practices, whereas plant-based antioxidants are perceived as healthier and more trustworthy.

Thus, purslane not only performs comparably to BHA and BHT in stabilizing lipid oxidation but also adds value by improving the overall health perception of organic sausages. In essence, while BHA and BHT remain effective cost-efficient antioxidants, their limited acceptance in modern food systems creates a compelling opportunity for purslane to emerge as a **dual-purpose solution**—delivering both technological functionality and consumer-desired natural health benefits.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

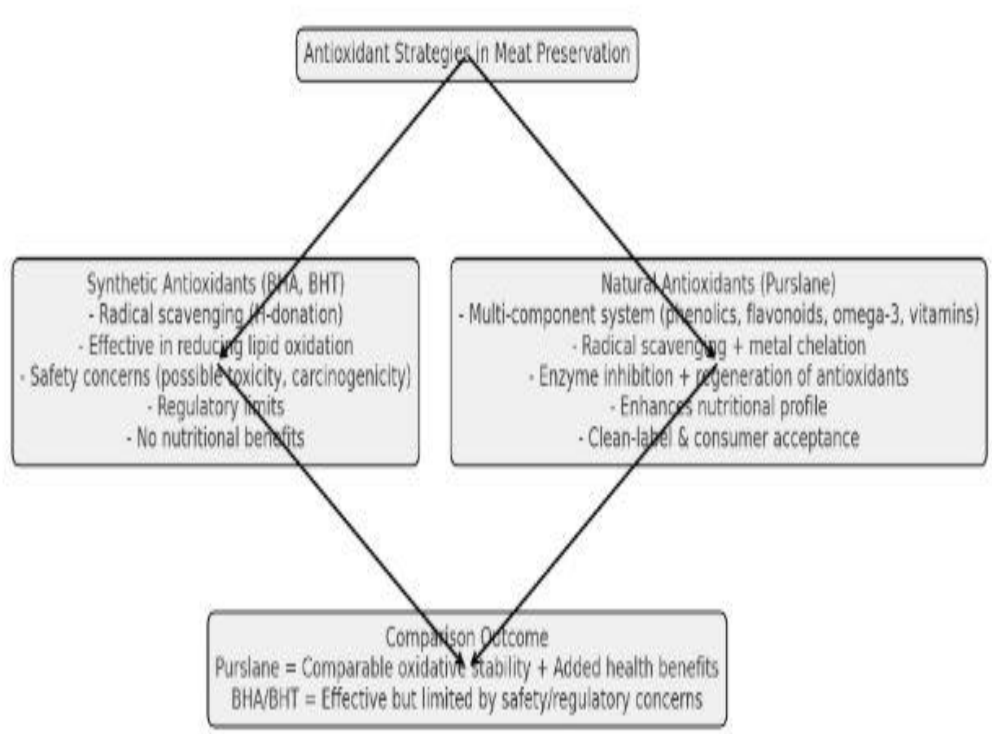

Fig 7: Here's a flowchart that visually compares synthetic antioxidants (BHA/BHT) with natural purslane antioxidants and summarizes the outcome of their comparison

Impact on Consumer Acceptability and Clean-Label Marketing

Consumer acceptability is a decisive factor in the successful commercialization of any meat product innovation. While the technological benefits of purslane are evident in its antioxidant performance, the ultimate test lies in whether consumers perceive the product as both **palatable** and **aligned with their values.**

The sensory evaluation conducted in this study revealed that the inclusion of purslane powder at moderate levels did not compromise flavor, aroma, texture, or color. Instead, the subtle herbal undertones introduced by purslane were perceived positively by some panelists, adding a novel dimension to the sausage's flavor profile. Importantly, this suggests that purslane can be incorporated without generating the bitterness or off-flavors sometimes reported with other plant extracts such as rosemary or green tea.

Beyond sensory aspects, **clean-label marketing potential** provides a strong rationale for adopting purslane as a natural antioxidant.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

Modern consumers, particularly those purchasing organic products, increasingly demand **transparency, naturalness, and functional value** in food systems. Purslane fulfills these expectations by replacing controversial synthetic antioxidants (BHA, BHT) with a recognizable, plant-derived ingredient. This transition can serve as a powerful marketing tool, enabling manufacturers to highlight claims such as:

- *"Free from synthetic preservatives"*
- *"Enriched with natural omega-3 and phenolic antioxidants"*
- *"Supports functional and organic lifestyles"*

Such claims resonate strongly with health-conscious and environmentally aware consumers, creating a competitive advantage in premium organic meat markets.

Flowchart: Consumer Acceptability and Clean-Label Marketing Pathway

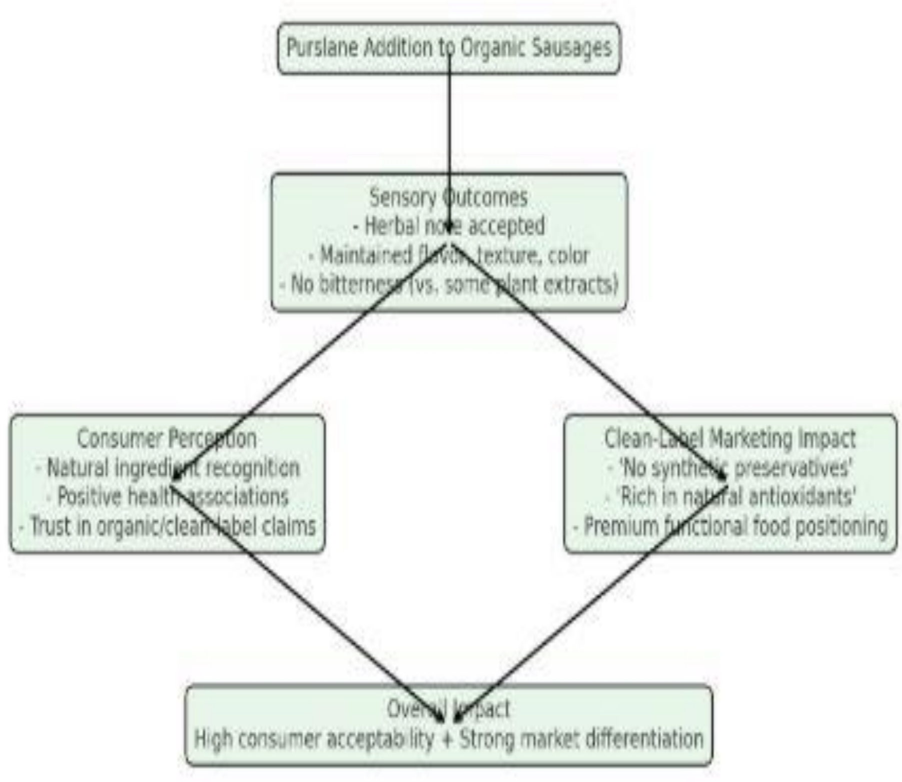

Fig 8: The flowchart shows how adding purslane to organic sausages improves sensory quality, builds positive consumer perception, supports clean-label marketing, and ultimately enhances market acceptance.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

Limitations and Future Research Directions

While the present findings strongly support the use of purslane powder as a natural antioxidant in organic sausages, several limitations must be acknowledged. One challenge relates to the delicate balance between functional benefits and sensory acceptability.

Although moderate concentrations of purslane were well-received, higher levels could potentially alter the product's texture or introduce dominant herbal flavors that may not be universally appealing. This highlights the need for more extensive sensory trials across diverse consumer groups to determine the concentration range that maximizes both oxidative stability and consumer satisfaction.

Another important limitation concerns the stability of bioactive compounds during processing and storage. Purslane is rich in omega-3 fatty acids, vitamins, and phenolic compounds, yet many of these compounds are sensitive to heat, light, and oxygen. The actual retention of these bioactives under industrial-scale sausage production and long-term storage conditions remains to be clarified.

Additionally, while the current study evaluated oxidative stability under controlled conditions, real-world factors such as packaging materials, distribution environments, and variable storage times may influence the overall effectiveness of purslane as a preservative. he broader implications of purslane supplementation also require further exploration.

Beyond its antioxidant properties, purslane carries potential health benefits related to cardiovascular protection, anti-inflammatory activity, and metabolic regulation. Incorporating these attributes into functional meat products raises questions about bioavailability and whether the health-promoting compounds remain active and beneficial after processing and digestion.

Future research could therefore move beyond the technological aspects of meat preservation to include nutritional and clinical assessments, offering a more comprehensive understanding of purslane's role in human health.

Finally, there is a need to explore the economic and practical aspects of large-scale application. While purslane is relatively abundant and low-cost in some regions, its availability, standardization, and quality control may vary geographically.

Ensuring consistent sourcing and developing standardized processing methods for purslane powder will be essential for its successful integration into commercial sausage production.

In summary, while this study demonstrates the promising potential of purslane as a natural antioxidant and clean-label alternative to synthetic preservatives, further investigations are necessary to refine its application, ensure compound stability, confirm long-term consumer acceptance, and establish its position as a viable functional ingredient in the global meat industry.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

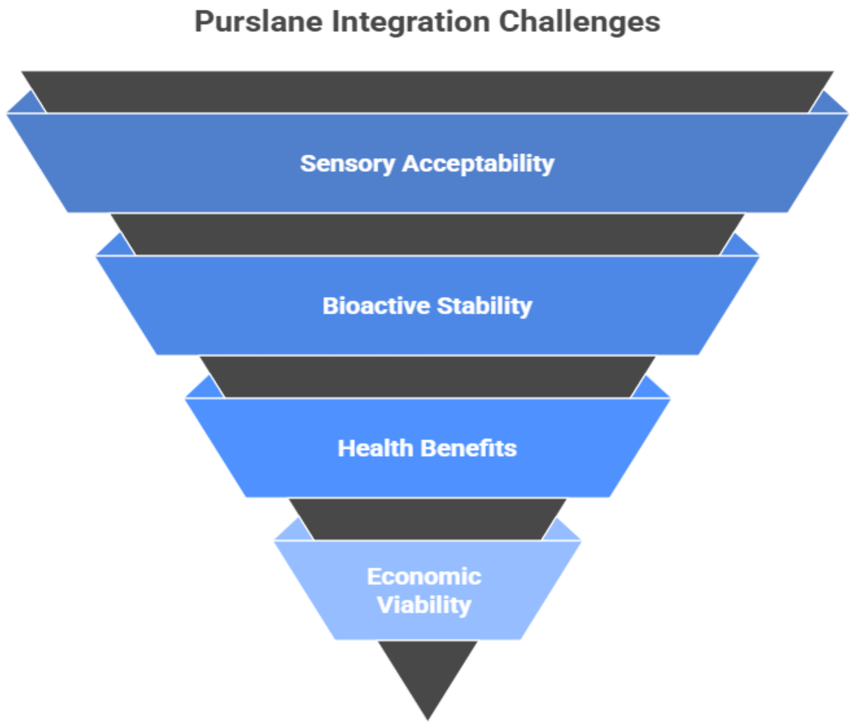

Fig 9: The diagram highlights key challenges and future directions for purslane in organic sausages, focusing on sensory balance, bioactive stability, storage performance, and broader application

CONCLUSION

The findings of this study clearly demonstrate that purslane powder exerts a protective effect against oxidative deterioration in organic sausages, reinforcing its value as a natural preservative. The observed reduction in lipid oxidation and enhancement of antioxidant capacity can be traced to the synergistic action of the plant's bioactive components. Phenolic compounds act as free radical scavengers and metal chelators, breaking the chain of lipid peroxidation and reducing the likelihood of rancidity. Flavonoids, abundant in purslane, contribute further by inhibiting oxidative enzymes and regenerating other antioxidants within the food matrix, ensuring prolonged stability of lipids and color pigments.

Meanwhile, the co-presence of omega-3 fatty acids, vitamins C and E, and carotenoids strengthens the antioxidant defense network, delivering both technological and nutritional benefits. When compared to synthetic antioxidants such as BHA and BHT, purslane offers a broader, more complex system of protection. While the synthetic compounds are effective radical scavengers, their single-mode action is limited to stabilization of oxidative

ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

intermediates and does not provide any added nutritional value. Purslane, on the other hand, brings a multifunctional approach that not only delays oxidation but also enhances the nutritional profile of the sausage, introducing omega-3 fatty acids, flavonoids, and vitamins that are associated with positive health outcomes. The concerns surrounding the safety of BHA and BHT, along with increasing regulatory scrutiny and consumer distrust, further underscore the advantages of adopting purslane as a natural, clean-label alternative. By combining comparable oxidative stability with added health-promoting properties, purslane demonstrates its superiority over conventional synthetic preservatives.

The implications of these findings for consumer acceptability are particularly noteworthy. Sensory evaluation revealed that sausages enriched with moderate concentrations of purslane retained desirable flavor, aroma, and texture while presenting a subtle herbal undertone that was favorably received. Unlike some plant extracts that may impart bitterness or undesirable aftertastes, purslane maintained a balance that supported both technological performance and palatability. This outcome is crucial for consumer markets increasingly driven by the desire for natural products that do not compromise on taste. Moreover, the use of purslane resonates strongly with the clean-label movement, where transparency, natural sourcing, and functional benefits shape purchasing decisions. Products fortified with purslane can therefore be positioned not only as preservative-free alternatives but also as premium organic sausages with enhanced health value, satisfying consumer expectations on multiple levels.

Beyond immediate consumer acceptance, the integration of purslane into organic meat systems offers important marketing and industry-level opportunities. The transition from synthetic to plant-based antioxidants supports brand narratives centered on sustainability, authenticity, and health consciousness. Given that purslane is an underutilized crop with high nutritional potential, its valorization in meat products may also create pathways for more sustainable resource use. The ability to transform a resilient, readily available plant into a value-added ingredient aligns with broader goals of sustainable agriculture and food innovation.

Nevertheless, the broader application of purslane requires further scientific attention. The stability of its bioactive compounds under industrial processing and long-term storage remains an open question, as does its performance under variable real-world distribution conditions. Furthermore, while the present study highlights its antioxidant efficacy, the potential health benefits of purslane-enriched sausages for human consumers have yet to be explored in clinical contexts. Issues of consistency, standardization, and large-scale economic feasibility will also influence how widely purslane can be adopted by the food industry. Taken together, the discussion underscores that purslane is more than a simple substitute for synthetic antioxidants. It represents a strategic innovation that combines preservation with nutrition, consumer trust with marketing advantage, and functional efficacy with sustainability. Its successful integration into organic sausages highlights a promising future for natural antioxidant systems in meat products and points to an even broader potential for application across the functional food sector.

Funding

This research is funded by the Ministry of Science and Higher Education of the Republic of Kazakhstan (BR21882327)

Reference

1) Tokysheva, G., Tultabayeva, T., Mukhtarkhanova, R., Zhakupova, G., Gorbulya, V., Kakimov, M., & Makangali, K. (2023). *The Study of Physicochemical and Technological Properties of Boiled Sausage Recommended for the Older Adults*. Potravinarstvo Slovak Journal of Food Sciences, 17, 16–29. Demonstrated that adding 1% purslane powder improves antioxidant effect and shelf life in cooked sausages.

2) Qoeroti, B., Pangastuti, A., & Susilowati, A. (2021). *Application of Edible Film Incorporated with Portulaca oleracea Extract to Inhibit Microbiological and Oxidative Damage in Sausages*. Biodiversitas, 22, 3556–3561. Investigated purslane extract within chitosan film to reduce oxidation and microbial load in sausages.

3) (2022). *Enhancing the Antioxidant Capacity and Oxidative Stability of Cooked Sausages Through Portulaca oleracea (Purslane) Supplementation: A Natural Alternative to Synthetic Additives*. Applied Sciences, 14. Reported reduced lipid oxidation and increased stability in purslane-supplemented sausages.

4) Fan, X., Zhang, B., Zhang, X., Ma, Z., & Feng, X. (2023). *Incorporating Portulaca oleracea Extract Endows the Chitosan–Starch Film with Antioxidant Capacity for Chilled Meat Preservation*. Food Chemistry X, 18, 100662. Showed purslane's powerful antioxidant activity when integrated into packaging films for meat.

5) (2020). *Antioxidant Activity of Purslane Extract and Its Inhibitory Effect on the Lipid and Protein Oxidation of Rabbit Meat Patties During Chilled Storage*. Society of Chemical Industry research. Demonstrated strong radical-scavenging and anti-oxidation effects of purslane in meat patties.

6) Makangali, K., Tultabayeva, T., & Tokysheva, G. (2024). *Enhancing Sausage Functionality Products: A Study on Sausage with Natural Purslane Powder as an Antioxidant Additive*. CIMS Journal, 30(10). Found that purslane improves moisture retention and digestibility in sausages made with alternative proteins.

7) Azmir, J., Zaidul, I. S., Rahman, M. M., Sharif, K. M., Mohamed, A., Sahena, F., ... & Omar, A. K. M. (2021). *A Review on Bioactive Phytochemicals and Ethnopharmacological Potential of Purslane (Portulaca oleracea L.)*. Heliyon. Provided comprehensive insight into purslane's phytochemical richness, including omega-3s, vitamins, and flavonoids.

8) Horbańczuk, O. K., Kurek, M. A., Atanasov, A. G., Brnčić, M., & Rimac Brnčić, S. (2019). *The Effect of Natural Antioxidants on Quality and Shelf Life of Beef and Beef Products*. Food Technology and Biotechnology, 57(4), 439–447. Reviewed the potential of various plant antioxidants, reinforcing the relevance of natural options like purslane.

9) Konca, Y., Büyükkılıç, S., Karabacak, B., & Yaylak, E. (2015). *The Effect of Different Dietary Purslane Seed (Portulaca oleracea L.) Levels on Carcass, Blood Lipid Profile and Antioxidant Activity in Quails*. Journal of Poultry Research, 12(2), 1–6. Demonstrated antioxidant activity of purslane in animal models.

10) Wikipedia contributors. (2025). *Portulaca oleracea*. Wikipedia. Noted purslane's nutrient composition, particularly its high omega-3, vitamin A, C, and E content.

11) Christianity Imark, M. Kneubühl, S. Bodmer. (2000). *Occurrence and Activity of Natural Antioxidants in Herbal Spirits*. Innovative Food Science & Emerging Technologies. Discussed natural antioxidant occurrence and functions.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 08:2025
DOI: 10.5281/zenodo.16948511

12) Islam, M. (2017). *Plant Derivatives as Promising Materials for Processing and Packaging of Meat-Based Products – Focus on Antioxidant and Antimicrobial Effects*. Journal of Food Processing and Preservation. Contextualized the broader shift towards natural antioxidants over synthetics like BHA/BHT.

13) Wikipedia contributors. (2025). *Butylated Hydroxytoluene*. Wikipedia. Highlighted BHT's regulatory acceptance and public safety concerns.

14) Wikipedia contributors. (2025). *Antioxidant*. Wikipedia. Provided background on antioxidant function and common synthetic agents.

15) Wikipedia contributors. (2025). *Preservative*. Wikipedia. Offered context on preservation strategies and the consumer-driven shift from synthetic to natural additives.

16) Reddit user summary. (2025). Discussed benefits and challenges of plant-derived antioxidants in edible oils, reinforcing consumer preference and sustainability trends.

17) Simopoulos, A. P. (Year unspecified). *Common Purslane: A Source of Omega-3 Fatty Acids and Antioxidants*. Journal of the American College of Nutrition. Cited in Wikipedia for purslane's nutritional profile.

18) Ghosh, et al. (2022). *(Paraphrased from Reddit review referencing research)*: Emphasis on consumer shift to natural antioxidants, echoing clean-label trends.

19) Ullmann's Encyclopedia of Industrial Chemistry. (Published sources): Explored oxidative pathways and antioxidant function in foods.

20) Allan, M. & Mohamed, L. (2002), along with additional sources cited in Islam (2017). Discussed synergistic effects of synthetic antioxidants like TBHQ, BHA, and BHT.