Asian Interdisciplinary and Sustainability Review

Original Research Article

Received: 19 January 2026 **Revised:** 11 May 2026 **Accepted:** 11 May 2026

EVALUATING ALTERNATIVE PACKAGING ON SHELF LIFE AND QUALITY OF WHOLE WHEAT BREAD

Boonyaporn CHUAMSOMPONG[1], Chanchana SIRIPANWATTANA[2*], Onanong THONGMEE[1] and Bussarakam SEEDALUANG[1]

1 School of Culinary Art, Suan Dusit University, Suphanburi Campus, Thailand; boonyaporn_chu@dusit.ac.th (B. C.)

2 Department of Home Bakery, Suan Dusit University, Thailand; chanchana_sir@gmail.com (C. S.) (Corresponding Author)

Handling Editor:
Professor Dr.Ramadan BASSIOUNY Minia University, Egypt
(This article belongs to Theme 2: Sciences and Technology for Sustainability)

Reviewers:
1) Professor Dr.Shashi Kant GUPTA Lincoln University College, Malaysia
2) Associate Professor Dr.Bounmy KEOHAVONG Souphanouvong University, Lao PDR.
3) Assistant Professor Dr.Paponpat PATTARATHITIWAT RMUTT, Thailand

Abstract

This study evaluates the shelf life of whole wheat bread and identifies optimal packaging materials based on product quality and consumer acceptance. The research compared two packaging variants: polyethylene terephthalate (PET) bags laminated with kraft paper and injected polypropylene (IPP) bags, storing the bread at 25 °C for seven days. Product quality evaluations involved physical, chemical, and microbiological analyses, while consumer acceptance was measured through a survey of 100 general consumers. The findings indicate that IPP packaging retained moisture more effectively, maintaining a softer, more elastic crumb structure, while PET packaging showed superior microbial control. After seven days, microbial counts in both packaging types remained within safety limits, with no pathogenic contamination detected, though lipid oxidation progressively increased over time. Crucially, the consumer survey revealed a strong preference for PET bags laminated with kraft paper because of their visual appeal, clear labeling, and appropriate sizing. Ultimately, this study concludes that PET packaging provides the optimal balance of microbial safety, quality preservation, and consumer satisfaction for whole wheat bread, supporting enhanced marketability and product longevity.

Keywords: Whole Wheat Bread, Shelf Life Evaluation, Polyethylene Terephthalate, Injected Polypropylene, Consumer Acceptance

Citation Information: Chuamsompong, B., Siripanwattana, C., Thongmee, O., & Seedaluang, B. (2026). Evaluating Alternative Packaging on Shelf Life and Quality of Whole Wheat Bread. *Asian Interdisciplinary and Sustainability Review, 15*(1), Article 14. https://doi.org/10.14456/aisr.2026.14

Introduction

Whole wheat bread is a brown baked product produced from whole wheat grains or unrefined wheat flour. It is widely recognized as a healthy food due to its rich content of essential nutrients, including dietary fiber, B-complex vitamins, vitamin E, minerals (such as calcium, iron, magnesium, potassium, and phosphorus), and antioxidants. Regular consumption of whole wheat bread has been associated with multiple health benefits, including improved glycemic control, reduced risk of cardiovascular disease, and a lower incidence of certain types of cancer.

Nutritionally, 100 g of whole wheat bread provides approximately 254 kcal of energy and contains 43.1 g of carbohydrates, 12.3 g of protein, and 3.55 g of fat. It is also a source of important micronutrients, including sodium (450 mg), potassium (250 mg), phosphorus (212 mg), calcium (163 mg), magnesium (76.6 mg), selenium (25.8 µg), choline (27.2 mg), and vitamins (55 mg) (Nutritiontable.com, n.d.). The high dietary fiber content of whole wheat bread contributes to weight management by enhancing satiety and supporting metabolic processes (Tangjaturonrasme, 2024). In addition, its low glycemic index makes it suitable for individuals with diabetes, while its fiber-rich composition helps reduce cholesterol absorption and supports cardiovascular health. Furthermore, whole grains and dietary fiber help reduce the risk of colorectal cancer. However, individuals with wheat allergies or gluten intolerance should avoid whole-wheat bread because it can cause adverse health effects.

Despite its nutritional advantages, the shelf life of whole-wheat bread is a critical factor in ensuring product quality and consumer safety. Initially, the product was packaged in a simple, clear plastic bag sealed with adhesive tape, which resulted in a relatively short shelf life and increased susceptibility to spoilage (Aravindan S et al., 2022). This limitation hindered market expansion and distribution potential. Consequently, this study focuses on evaluating two alternative packaging materials considered suitable for whole wheat bread: (1) a clear plastic bag laminated with kraft paper, consisting of an outer layer of clear PET film coated with kraft paper, and (2) an injected polypropylene (IPP) plastic bag. In addition, consumer perceptions of the packaging were assessed to support the development of a standardized, high-quality packaging solution (Paklamjeak, 2021). Therefore, this research aims to investigate the shelf life and identify appropriate packaging materials for whole wheat bread products.

Literature Reviews

Whole wheat bread has gained popularity owing to its well-established health benefits, including higher fiber, vitamin, and mineral content than refined white bread. These nutritional benefits largely stem from incorporating bran and germ, which increase the product's antioxidant and micronutrient content. However, these same attributes also make whole wheat bread more prone to quality deterioration and accelerated decomposition, presenting considerable challenges for shelf life and storage stability.

Spoilage Mechanisms and Shelf Life

Complex microbiological, physical, and chemical mechanisms predominantly drive spoilage in whole wheat bread. The primary factor limiting freshness is microbial deterioration—most notably the rapid proliferation of molds such as Penicillium, Aspergillus, and Rhizopus in the bread's moist environment, further exacerbated by the nutrient-dense bran and germ, which provide a rich substrate for fungal growth (Zhou, 2014). Physically, the bread undergoes staling, characterized by increased crumb stiffness and decreased flexibility due to amylopectin retrogradation and recrystallization, along with moisture migration from the crumb to the crust (Fadda et al., 2014; Hug-Iten et al., 2003). Furthermore, chemical spoilage occurs through lipid oxidation, driven by the higher concentration of unsaturated lipids in the germ and bran, which oxygen and light accelerate, leading to rancidity and hazardous peroxides. These interacting mechanisms highlight how environmental factors, particularly humidity and temperature,

dictate the bread's physical texture and its susceptibility to microbial and chemical degradation (Rahman et al., 2022).

The Role of Packaging: Comparison Between PP and PET

Selecting appropriate packaging is critical to mitigating these spoilage processes by providing robust barriers against moisture, oxygen, and microbial contamination (Muizniece-Brasava et al., 2012). While polypropylene (PP) is frequently utilized for its cost-effectiveness, flexibility, and mild barrier properties that delay staling and moisture loss for 5-7 days, its relatively high oxygen transmission rate leaves products vulnerable to lipid oxidation and mold development during extended storage (Novotni et al., 2011; Tan et al., 2021). In contrast, polyethylene terephthalate (PET) offers a high-performance alternative with a denser molecular structure, yielding superior impermeability to gases and moisture. Research demonstrates that PET packaging significantly curtails aerobic bacterial growth, mitigates rancidity, and retards mold development, thereby preserving the bread's original flavor and softness longer than PP-packaged or unpackaged alternatives (Rahman et al., 2022; Tinnabutr, 1988). To overcome the practical limitations of PET, such as reduced flexibility and higher costs, recent advancements emphasize hybrid approaches—such as PP/PET laminates—or the integration of scavengers and antibacterial agents to maximize protective efficacy, minimize deterioration, and ensure optimal consumer safety (Phuwarodom, 2007; Østergaard & Hanssen, 2018).

Research Methodology

Sample Preparation and Storage Protocol

Whole wheat bread was formulated with 500 g bread flour, 500 g whole wheat flour, 575 g water, 10 g yeast, 40 g fresh butter, 30 g granulated sugar, and 8 g salt. After mixing into a homogeneous dough and resting for 20 minutes, the dough was divided into 300 g portions, proofed until doubled in volume, and baked at 200 °C for 45 minutes. Upon cooling at ambient temperature, the loaves were uniformly sliced to a 1 cm thickness. To evaluate shelf life, the slices were packaged in two distinct materials: polyethylene terephthalate (PET) bags laminated with kraft paper, and injected polypropylene (IPP) plastic bags. These packaged samples were then stored in sealed containers at a controlled ambient temperature of 25 °C for seven days, during which quality changes were systematically monitored.

Analytical Procedures and Consumer Evaluation

The bread samples underwent comprehensive physical, chemical, and consumer assessments. Physical evaluations included colorimetric measurements (L*, a*, b*) using an AR-F701 colorimeter, alongside texture profile analyses—assessing hardness, springiness, and cohesiveness—conducted with a TA.XT.Plus texture analyzer. Chemical stability was determined by measuring moisture content via the hot air oven method utilizing a Memmert oven. Lipid oxidation was quantified by calculating the peroxide value (PV) through sodium thiosulfate titration. Concurrently, packaging acceptance was assessed through a structured survey administered to 100 general consumers, capturing demographic profiles and specific evaluations of packaging attributes to determine the optimal material for commercial application.

Statistical Analysis

The analytical phase integrated rigorous microbiological safety evaluations, inferential statistics, and descriptive consumer data. The shelf life of the whole wheat bread was determined based on a seven-day microbial quality analysis—encompassing total plate counts and yeast and mold counts in accordance with AOAC methods (Association of Official Analytical Chemists, 2000)—and strictly evaluated against safety criteria for Salmonella spp., Staphylococcus aureus, Bacillus cereus, and Clostridium perfringens. The experimental data concerning physical and chemical quality were structured using a Randomized Complete Block Design (RCBD). These data were analyzed using Analysis of Variance (ANOVA), and

statistically significant differences among treatments were resolved using Duncan's New Multiple Range Test (DNMRT) at a 95% confidence level. Concurrently, quantitative data regarding consumer acceptance to determine the most appropriate packaging materials were analyzed using descriptive statistics, including percentages, means, and standard deviations.

Research Ethics Translation

Research Ethics Committee, Suan Dusit University Certificate of Approval Number: HS.009/2568 Date of Issue: May 20, 2025

Research Results

Physical Characteristics: Color Stability and Textural Integrity

The color attributes (L*, a*, b*) of whole wheat bread packaged in both PET and IPP bags showed minimal fluctuations during the seven-day evaluation, maintaining a bright, uniform appearance. Statistical analyses revealed no significant differences in redness/greenness (a*), and comparative assessments confirmed that neither packaging material significantly altered the bread's baseline color stability during short-term storage.

Table 1 Results of color analysis L* a* b* of Whole wheat bread products in PET bags and IPP bags

Day	PET bag			IPP bag		
	L* Bright	a* Red	b* Yellow	L* Bright	a* Red	b* Yellow
1	$70.79^{b}\pm0.25$	$3.05^{a}\pm0.19$	$18.05^{c}\pm0.26$	$70.13^{b}\pm0.23$	$3.52^{ab}\pm0.22$	$18.47^{b}\pm0.17$
2	$71.55^{a}\pm0.14$	$3.06^{a}\pm0.24$	$17.59^{c}\pm0.28$	$71.77^{a}\pm0.21$	$3.14^{b}\pm0.31$	$17.97^{b}\pm0.13$
3	$69.92^{d}\pm0.12$	$3.13^{a}\pm0.17$	$18.16^{c}\pm0.19$	$70.32^{b}\pm0.28$	$3.88^{a}\pm0.27$	$19.22^{a}\pm0.24$
4	$69.96^{d}\pm0.20$	$3.30^{a}\pm0.32$	$18.77^{b}\pm0.22$	$70.62^{ab}\pm0.19$	$3.53^{ab}\pm0.19$	$19.57^{a}\pm0.21$
5	$70.70^{c}\pm0.25$	$3.57^{a}\pm0.25$	$20.12^{a}\pm0.20$	$70.04^{b}\pm0.25$	$3.46^{ab}\pm0.24$	$19.12^{a}\pm0.18$
6	$71.69^{a}\pm0.16$	$3.09^{a}\pm0.18$	$17.64^{c}\pm0.15$	$71.12^{a}\pm0.15$	$3.52^{ab}\pm0.20$	$18.66^{b}\pm0.20$
7	$70.01^{d}\pm0.24$	$3.13^{a}\pm0.23$	$18.90^{b}\pm0.17$	$69.93^{b}\pm0.26$	$3.61^{ab}\pm0.25$	$19.00^{ab}\pm0.15$

Note: a, b, c. Different letters in the vertical direction indicate a statistically significant difference at the 95% confidence level.

Texture profile analyses indicated that bread packaged in PET bags maintained relatively stable structural parameters, with hardness (0.87–1.21 N), springiness (5.28–7.55 mm), and cohesiveness (0.46–0.64) exhibiting no statistically significant degradation ($p > 0.05$) over the storage duration.

Table 2 Texture values of whole wheat bread products, PET bags

Day	Texture		
	Hardness (N)	Springiness (mm)	(Cohesiveness)
1	$0.87^{ns}\pm0.28$	$7.55^{ns}\pm0.79$	$0.64^{ns}\pm0.14$
2	$0.90^{ns}\pm0.25$	$7.12^{ns}\pm0.57$	$0.57^{ns}\pm0.20$
3	$0.94^{ns}\pm0.31$	$6.65^{ns}\pm0.95$	$0.53^{ns}\pm0.17$
4	$1.07^{ns}\pm0.26$	$6.49^{ns}\pm1.05$	$0.50^{ns}\pm0.15$
5	$1.09^{ns}\pm0.32$	$6.10^{ns}\pm0.98$	$0.49^{ns}\pm0.09$
6	$1.14^{ns}\pm0.14$	$5.73^{ns}\pm0.83$	$0.47^{ns}\pm0.15$
7	$1.21^{ns}\pm0.34$	$5.28^{ns}\pm0.75$	$0.46^{ns}\pm0.11$

Note: a, b, c. Different letters in the vertical direction indicate a statistically significant difference at the 95% confidence level.

Conversely, bread packaged in IPP bags demonstrated a progressive increase in hardness (0.76–1.57 N), coupled with a gradual decline in both springiness and cohesiveness. These dynamic changes signify the development of a denser crumb structure and a corresponding reduction in overall structural integrity over time.

Table 3 Texture values of whole wheat bread products, IPP bags

Day	Texture		
	Hardness (N)	**Springiness (mm)**	**Cohesiveness**
1	0.76^{bc}±0.18	7.89^{a}±0.75	0.68^{a}±0.12
2	0.85^{b}±0.24	7.53^{ab}±0.72	0.65^{a}±0.15
3	0.89^{bc}±0.33	7.54^{ab}±0.70	0.62^{ab}±0.23
4	0.91^{bc}±0.35	6.67^{b}±0.84	0.56^{ab}±0.15
5	0.95^{b}±0.24	6.64^{b}±0.89	0.54^{ab}±0.17
6	1.03^{ab}±0.37	6.38^{b}±0.83	0.51^{b}±0.20
7	1.57^{a}±0.29	6.50^{b}±0.73	0.48^{b}±0.18

Note: a, b, c. Different letters in the vertical direction indicate a statistically significant difference at the 95% confidence level.

Moisture Retention and Chemical Degradation

A comparative analysis showed that IPP packaging retained moisture significantly better than PET packaging. The accelerated moisture loss in PET-packaged bread directly correlated with its firmer, more brittle crumb structure and distinct reductions in elasticity, primarily driven by starch retrogradation. Consequently, IPP packaging proved vastly superior at preserving the bread's internal moisture and extending its desirable textural properties.

Table 4 Moisture analysis results of whole wheat bread products packed in PET bags and IPP bags

Day	Moisture value (%)	
	PET bags	**IPP bags**
1	43.25^{a}±1.25	44.31^{a}±1.27
2	42.85^{a}±1.40	43.36^{a}±1.18
3	41.48^{ab}±1.32	42.42^{ab}±1.25
4	40.24^{b}±1.42	42.18^{ab}±1.32
5	39.18^{bc}±1.30	41.93^{ab}±1.28
6	37.75^{c}±1.15	41.11^{b}±1.19
7	36.59^{c}±1.34	39.39^{b}±1.16

Note: a, b, c. Different letters in the vertical direction indicate a statistically significant difference at the 95% confidence level.

Shelf Life Evaluation Based on Microbial Quality

We evaluated the shelf life of whole wheat bread packaged in PET and IPP bags over a 7-day storage period based on microbial quality analyses. Microbial assessments included total plate count and yeast and mold count, conducted according to AOAC methods (Association of Official Analytical Chemists, 2000). We also examined foodborne pathogens to assess product safety.

For bread packaged in PET bags, microbial analysis revealed a total plate count of 7.2×10^{3} CFU/g and a yeast and mold count of 4.3×10^{1} CFU/g at the end of the storage period. Pathogenic microorganisms, including Salmonella spp. (not detected in 25 g), Clostridium perfringens, Staphylococcus aureus, and Bacillus cereus (all not detected in 1 g), were absent from the samples.

Similarly, whole wheat bread packaged in IPP bags exhibited a total plate count of 1.1×10^4 CFU/g and a yeast and mold count of 8.0×10^1 CFU/g after 7 days of storage. No detection of Salmonella spp. (in 25 g) Alternatively, C. perfringens, S. aureus, and B. cereus (in 1 g) were observed. Overall, both packaging types maintained microbial counts within acceptable safety limits throughout the 7-day storage period, with no pathogenic contamination detected. The detailed microbial quality results are presented in Table 5.

Table 5 Microbial count in packaging, PET bags and IPP bags of whole wheat bread products for 7 days stored at room temperature.

Packaging	Quantity of microorganisms (CFU/g)					
	Total Viable Count	**Yeast and Mold**	**Salmonella spp.**	**Clostridium perfringens**	**Staphy Lococcus aureus**	**Bacillus cereus**
PET bag	$7.2x10^3$	4.3x10	ND	ND	ND	ND
IPP bag	$1.1x10^4$	8.0x10	ND	ND	ND	ND

Note: ND: Not Detected = No microorganisms were detected; 10 = Fungi detected not more than 10 colonies/gram.

Chemical Quality Analysis: Peroxide Value (PV)

The chemical quality of whole wheat bread packaged in PET and IPP bags was evaluated by measuring peroxide value (PV) as an indicator of lipid oxidation. The average PV of bread stored in PET bags was 4, while that of bread stored in IPP bags was 5. At the initial stage of storage, PV values for all samples were comparable; however, PV increased progressively with extended storage time.

After one week of storage, an increasing tendency toward oxidative spoilage was observed, characterized by the development of rancid odors and a decline in product acceptability. These results indicate that prolonged storage promotes lipid oxidation, which may compromise the bread's safety and sensory quality.

The observed increase in PV is consistent with Poljsak et al. (2021), who reported that oxidative processes, particularly those influenced by light exposure, can degrade food components such as vitamins, proteins, and antioxidants. This degradation contributes to rancid odors and undesirable color changes. The extent of these oxidative changes depends on the light absorption characteristics of food constituents and increases with storage duration. Figure 1 illustrates the PV trends observed in this study.

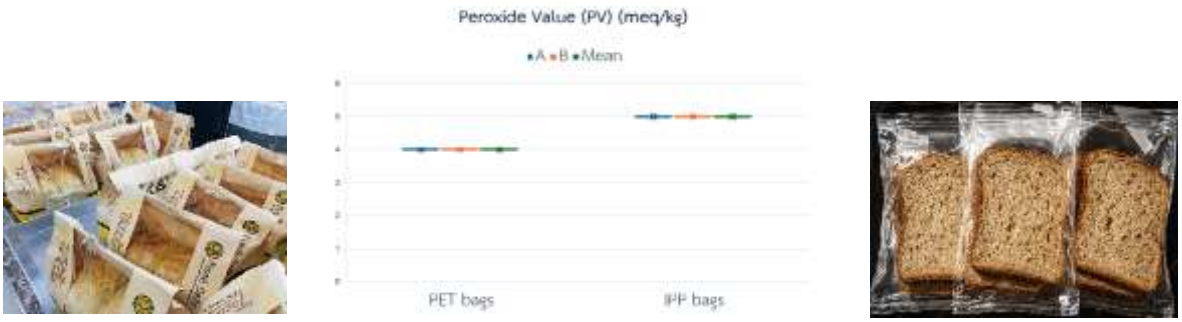


Figure 1 Peroxide Value (PV) of packaging of whole wheat bread products

Consumer Characteristics and Packaging Acceptance

The consumer survey respondents comprised 49% males and 51% females. In terms of age distribution, 49% of respondents were under 20 years old, followed by those aged 21-30 years (26%). Respondents aged 31-40 years accounted for 14%, while those aged 41-50 years

represented 8%. Smaller proportions were observed in the 51-60 age group (2%) and those aged over 60 years (1%). Regarding educational attainment, 6% of respondents held doctoral degrees, 24% held master's degrees, and the remaining 70% had bachelor's degrees or lower. In terms of occupation, most respondents were students (33%), followed by private business owners (21%), traders (16%), employees in state enterprises (14%), private-sector employees (11%), and other occupations (5%). The demographic characteristics of the respondents are illustrated.

Consumer acceptance data related to whole wheat bread packaging are presented. The results indicated that packaging in a clear plastic bread bag laminated with kraft paper received the highest mean acceptance score (4.62). The packaging label was also highly rated (mean = 4.50), followed by an appropriate package size to improve transportation efficiency (mean = 4.40). The inclusion of silica gel desiccant received high acceptance (mean = 4.30), and ease of opening for consumption was also positively evaluated (mean = 4.10).

Moderate acceptance was observed for packaging containing preservatives and for packaging in IPP (injected polypropylene) bakery bags (mean = 3.90). Packaging attributes related to maintaining bread quality (mean = 3.80) and to clearly displaying the bread's shape (mean = 3.60) were rated as very acceptable. The figure illustrates overall consumer acceptance trends for packaging attributes.

Conclusion and Discussion

This study systematically evaluated the efficacy of PET and IPP packaging materials in preserving the shelf life and quality of whole wheat bread. Physical assessments showed that while both packaging types maintained color stability (L*, a*, b*) over the seven-day storage period without significant degradation, their effects on textural integrity differed considerably. Textural and chemical analyses showed that IPP packaging retained moisture better, yielding a softer, more elastic, and highly cohesive crumb structure. Conversely, bread stored in PET bags experienced more pronounced moisture migration, resulting in increased crumb hardness, reduced springiness, and heightened brittleness. These observations align directly with established staling mechanisms—specifically starch retrogradation and gluten weakening—where moisture loss intrinsically accelerates structural degradation and potential non-enzymatic browning reactions during extended storage, collectively compromising overall product quality (Fadda et al., 2014; Hug-Iten et al., 2003; Lekjing & Venkatachalam, 2019; Wani & Kumar, 2016).

Despite the textural advantages of IPP packaging, microbiological and chemical evaluations underscore PET's superior protective qualities. Throughout storage, both materials kept microbial counts well within acceptable safety limits, with no pathogenic contamination detected. However, PET packaging maintained markedly lower total microbial, yeast, and mold counts than IPP. This enhanced microbial control likely stems from PET's higher gas permeability, which regulates internal humidity and limits conditions favorable for fungal proliferation. In contrast, IPP's strict moisture retention creates a microenvironment highly conducive to microbial growth (Zhou, 2014). Concurrently, both packaging systems exhibited a progressive increase in peroxide values (PV), signaling the onset of lipid oxidation and oxidative rancidity over time, a degradation pathway similarly documented by Poljsak et al. (2021) regarding prolonged light and oxygen exposure.

Beyond physicochemical and microbial performance, consumer acceptance remains a critical determinant for commercial viability. Demographic surveys revealed that consumers—predominantly young adults and students—strongly preferred the PET bags laminated with kraft paper, consistently awarding the highest acceptance scores for the packaging's visual appeal, clear labeling, convenience, and optimally designed size. These preferences corroborate the findings of Ilmia & Mahmudah (2024), emphasizing that modern food

packaging must successfully balance aesthetic distinctiveness with safety, informative labeling, and structural convenience.

In evaluating the optimal packaging solution, this study demonstrates a clear divergence in material performance. While IPP packaging offers distinct advantages in moisture retention and prolonged textural preservation, PET packaging delivers superior microbial control and secures significantly higher consumer acceptance. Consequently, selecting the most appropriate packaging for whole wheat bread requires a strategic balance between maintaining textural quality, ensuring microbial safety, and satisfying consumer aesthetic preferences to maximize both shelf life and market viability, a conclusion robustly supported by the packaging optimization principles outlined by Alhendi & Choudhary (2013). Furthermore, although composite laminated materials pose certain recycling challenges, their ability to extend product shelf life drastically plays a critical role in sustainability by effectively minimizing global food waste. Moving forward, strategically developing bio-based laminates to replace traditional PET offers a promising pathway to meet rigorous food safety requirements while advancing modern recycling standards.

References

Alhendi, A., & Choudhary, R. (2013). Current Practices in Bread Packaging and Possibility of Improving Bread Shelf Life by Nanotechnology. *International Journal of Food Science and Nutrition Engineering, 3*(4), 55-60.

Aravindan, S., Selvam, S., Subramaniyan, V., Subramanian, S., & Sathiavelu, M. (2022). Bread packaging techniques and trends. *Italian Journal of Food Safety, 11*(4), 10771.

Association of Official Analytical Chemists. (2000). *Official Methods of Analysis of AOAC International* (17th ed.). Maryland: Association of Official Analytical Chemists.

Fadda, C., Sanguinetti, A., del Caro, A., Collar, C., & Piga, A. (2014). Bread Staling: Updating the View. *Comprehensive Reviews in Food Science and Food Safety, 13*(4), 473-492.

Hug-Iten, S., Escher, F., & Conde-Petit, B. (2003). Staling of Bread: Role of Amylose and Amylopectin and Influence of Starch-Degrading Enzymes. *Cereal Chemistry, 80*(6), 654-661.

Ilmia, R., & Mahmudah, N. (2024). Evaluating the impact of packaging types on Bread quality and shelf life. *Journal of Innovation Food and Animal Science, 1*(1), 19-24.

Lekjing, S., & Venkatachalam, K. (2019). Influences of storage time and temperature on sensory and measured quality of green gram savory crackers. *LWT - Food Science and Technology, 113*, 108310.

Muizniece-Brasava, S., Dukalska, L., Murniece, I., Dabina-Bicka, I., Kozlinskis, E., Sarvi, S., Santars, R., & Silvjane, A. (2012). Active Packaging Influence on Shelf Life Extension of Sliced Wheat Bread. *International Scholarly and Scientific Research & Innovation, 6*(7), 480-486.

Novotni, D., Ćurić, D., Galić, K., Škevin, D., Neđeral, S., Kraljić, K., … & Ježek, D. (2011). Influence of frozen storage and packaging on oxidative stability and texture of bread produced by different processes. *LWT - Food Science and Technology, 44*(3), 643-649.

Nutritiontable.com. (n.d.). *Nutritional information Bread, whole-wheat*. Retrieved from www.nutritiontable.com/nutritions/nutrient/?id=652.

Østergaard, S., & Hanssen, O. (2018). Wasting of Fresh-Packed Bread by Consumers—Influence of Shopping Behavior, Storing, Handling, and Consumer Preferences. *Sustainability, 10*, 2251.

Paklamjeak, M. (2021). Packaging Technology for Shelf Life Extension of Food Products. *Journal of Learning Innovation and Technology, 1*(2), 12-22.

Phuwarodom, N. (2007). *Food packaging*. Bangkok: Kasetsart University Press.

Poljsak, B., Kovač, V., & Milisav, I. (2021). Antioxidants, Food Processing and Health. *Antioxidants, 10*(3), 433.

Rahman, M., Islam, R., Hasan, S., Zzaman, W., Rana, M., Ahmed, S., … & Sunny, A. (2022). A Comprehensive Review on Bio-Preservation of Bread: An Approach to Adopt Wholesome Strategies. *Foods, 11*(3), 319.

Tan, C., Han, F., Zhang, S., Li, P., & Shang, N. (2021). Novel Bio-Based Materials and Applications in Antimicrobial Food Packaging: Recent Advances and Future Trends. *International Journal of Molecular Sciences, 22*(18), 9663.

Tangjaturonrasme, P. (2024). *Nutrition for Health*. Bangkok: Phramongkutklao Hospital.

Tinnabutr, P. (1988). *Packaging design*. Bangkok: Odeon Store Publishing.

Wani, S., & Kumar, P. (2016). Moisture sorption isotherms and evaluation of quality changes in extruded snacks during storage. *LWT - Food Science and Technology, 74*, 448-455.

Zhou, W. (ed.). (2014). *Bakery Products Science and Technology* (2nd ed.). New Jersey: Wiley-Blackwell.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or a claim that its manufacturer may make, is not guaranteed or endorsed by the publisher.

Copyright: © 2026 by the authors. This is a fully open-access article distributed under the terms of the Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0).