

Geometric Design of Bread in Iran:

A Mathematical Approach to Waste Reduction and

Supply Chain Efficiency

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Abstract

Bread remains a cornerstone of the Iranian diet, yet the nation continues to face persistent challenges related to flour utilization and bread waste. Although the cultural and nutritional dimensions of bread have been widely documented, the influence of geometric design on production efficiency and post-consumption waste has received limited scholarly attention. This study adopts a mathematical and engineering-oriented approach to investigate how bread geometry affects production, packaging, storage, and shelf life across Iranian and international contexts. By analyzing traditional Iranian breads—Sangak, Barbari, Lavash, and Taftoon—and comparing them with representative global varieties such as the French baguette, Japanese shokupan, Mexican tortilla, and Indian naan, this paper establishes the relationship between geometric form, surface-to-volume ratio (S/V), and Packaging Index (PI). The findings demonstrate that geometric configuration critically determines flour efficiency, moisture retention, and packaging optimization. Mathematical modeling based on S/V analysis reveals that breads with lower ratios exhibit slower staling rates and higher storage efficiency. Simulation results suggest that moderately thick, rectangular flatbreads with controlled perforations could reduce bread waste in Iran by approximately 15–20%, aligning traditional cultural preferences with modern supply chain efficiency. The study ultimately highlights

bread geometry as a quantifiable and underutilized lever for waste reduction, providing evidence-based insights for bakers, policymakers, and food engineers to advance sustainability in the Iranian bread system.

Keywords: Bread geometry; Mathematical modeling; Food engineering; Waste reduction; Supply chain efficiency; Shelf life optimization

1. Introduction

Bread is one of the most essential staple foods worldwide and constitutes a cornerstone of daily nutrition in Iran, transcending social classes and age groups [1,2]. Wheat flour remains one of the most subsidized commodities in the country; however, persistent inefficiencies in flour utilization and bread consumption have generated both economic and environmental challenges. These challenges are consistent with global evidence showing that a substantial proportion of food is lost or wasted across production, distribution, and household stages [10]. While factors such as baking techniques, storage conditions, and consumer behavior are frequently discussed in the literature, one critical yet underexplored dimension is the geometric design of bread.

Food geometry exerts a profound influence on production efficiency, packaging density, handling, and shelf life. Physical parameters such as surface-to-volume ratio (S/V), thickness, and shape uniformity determine the rate of staling and moisture loss, thereby affecting the overall level of waste [2,5]. Breads with high S/V ratios—typical of thin flatbreads—lose moisture rapidly and exhibit reduced storability, whereas standardized loaves with lower S/V ratios offer advantages in packaging, stacking, and long-term freshness [2]. From a food engineering perspective, the chemical and physical processes of staling are accelerated by increased surface exposure, which enhances volatile compound loss and textural degradation [4].

Traditional Iranian breads exhibit remarkable geometric diversity. Sangak, a long and irregularly oval flatbread baked on hot stones, presents difficulties in standardization and packaging. Barbari is thicker and roughly rectangular but often lacks dimensional consistency across bakeries. Lavash, extremely thin and circular, becomes stale quickly if not consumed immediately. Taftoon lies between Lavash and Barbari in both thickness and flexibility but remains geometrically suboptimal for industrial packaging and mechanized transport. While these varieties hold significant cultural and historical importance, their irregular geometries contribute to measurable inefficiencies throughout Iran's flour economy and bread supply chain.

International comparisons further demonstrate the connection between bread geometry and supply chain optimization. The French baguette, though elongated and cylindrical, achieves excellent crust formation but requires near-daily consumption due to its high S/V ratio [3]. The Japanese shokupan exemplifies the benefits of

geometric uniformity; its cubical form supports slicing, packaging, and longer storage [6]. Mexican tortillas, while thin, minimize waste through functional design—serving as edible wraps that reduce post-consumer losses [7]. Collectively, these examples underscore how the geometric configuration of bread directly influences sustainability, waste levels, and logistical efficiency within national food systems.

From a mathematical standpoint, bread geometry can be rigorously analyzed using S/V ratio models, packing density formulas, and optimization algorithms to quantify how shape characteristics—such as curvature, aspect ratio, and uniformity—affect staling kinetics and logistics [5,8]. For instance, rectangular or loaf-shaped breads minimize void spaces in packaging and transport, thereby increasing storage density and reducing damage. Moderate thickness further mitigates moisture loss by balancing crust development and internal humidity retention. Simulation-based modeling offers predictive insights into how modified bread geometries can reduce flour waste under real-world production and consumption constraints [8].

Despite these theoretical and empirical insights, few Iranian studies have systematically addressed bread geometry as a determinant of waste reduction. The majority of prior research has focused on agricultural productivity, flour quality, and consumer habits, leaving a gap in understanding the geometric–engineering nexus within Iran’s bread economy [1,2,9]. This study aims to fill that gap by integrating mathematical reasoning with food engineering to evaluate the role of bread shape in optimizing efficiency and minimizing waste.

Accordingly, the research pursues three specific objectives:

1. To analyze the geometric properties of traditional Iranian breads and compare them with international varieties.
2. To apply mathematical modeling, particularly surface-to-volume (S/V) analysis, to assess how bread shape influences waste generation and storage efficiency.
3. To propose geometry-based recommendations that respect Iran’s cultural bread traditions while enhancing production, packaging, and supply-chain sustainability.

2. Literature Review

Bread has long been recognized as one of humanity’s most fundamental and symbolically significant food products. Extensive academic research has explored bread from cultural, nutritional, and technological perspectives. However, the geometric characteristics of bread—including form, thickness, and structural uniformity—have received considerably less attention in the literature, despite their measurable effects on food waste and supply chain efficiency.

Scholars in food science and food engineering have consistently emphasized the dual role of bread as both a dietary staple and an indicator of food security [4]. Western

studies have traditionally focused on biochemical and technological aspects, such as improving texture, flavor, and shelf life through fermentation control and ingredient optimization [5]. In contrast, Middle Eastern research has largely examined the cultural and nutritional dimensions of bread consumption [6], often overlooking the implications of its physical and geometric properties for efficiency and waste.

In Europe and North America, one notable research strand addresses the influence of loaf shape and geometry on packaging and transport efficiency. Pomeranz [7] was among the first to identify that variation in loaf dimensions substantially affects both production logistics and post-baking handling. More recent studies, such as Smith et al. [8], have quantitatively analyzed the relationship between geometric compactness and storage density, concluding that uniform, rectangular geometries minimize packaging voids and reduce mechanical damage during distribution.

In contrast, bread-related research in Iran and neighboring Middle Eastern countries has focused primarily on agricultural productivity, fermentation techniques, and consumer behavior rather than geometric optimization [9,10]. These works provide valuable insight into the quality, nutrition, and socio-economic role of bread but fail to model its physical structure mathematically. However, comparative studies in India have begun bridging this gap. Gupta and Verma [11] applied computational modeling to analyze flatbread geometry, demonstrating how optimizing thickness and curvature can significantly reduce flour waste in large-scale production systems.

Cross-cultural analyses have also revealed meaningful behavioral differences in bread consumption and disposal. In most Western societies, sliced square bread dominates daily consumption, providing geometric uniformity that simplifies packaging and extends shelf life [12]. Conversely, in Iran, round or oval-shaped flatbreads such as Lavash and Sangak remain prevalent. While culturally integral, these traditional shapes hinder efficient packaging, accelerate staling, and ultimately contribute to higher rates of bread waste [13].

Pioneering research in the late 20th century began to frame flatbread technology within a systematic scientific context. Faridi and Faubion [14] highlighted the technological and geometric factors influencing flatbread quality, marking an early step toward integrating geometry into bread engineering. Subsequent studies in modern food engineering [15] have developed mathematical optimization models to simulate baking conditions and predict the impact of geometric features on bread performance—though most such work has focused on Western industrial settings.

Collectively, the reviewed literature establishes several key insights:

1. Bread geometry is a determinant of both staling kinetics and packaging efficiency, yet remains underrepresented in academic research.
2. A significant geographic imbalance exists between Western and Middle Eastern scholarship, with limited attention to geometric modeling in Iran.
3. Recent advances in computational food engineering demonstrate that shape optimization can serve as a powerful tool for waste reduction and supply-chain efficiency.

In summary, although the scientific literature thoroughly addresses the cultural, nutritional, and technological aspects of bread, there remains a substantial research gap concerning geometric modeling as a mechanism for waste reduction—particularly in the Iranian context. The present study seeks to fill this void by combining mathematical modeling, cross-country comparison, and engineering analysis to elucidate how bread geometry can serve as a quantitative, policy-relevant factor in improving Iran's bread system efficiency.

3. Methodology

3.1. Overview

The primary objective of this study is to investigate the relationship between bread geometry and food waste in Iran through a mathematical modeling framework. To this end, the methodology integrates analytical modeling, cross-country data collection, and comparative benchmarking. The approach enables a systematic evaluation of geometric properties, such as thickness and shape, and their direct effects on shelf life, packaging efficiency, and waste reduction.

3.2. Mathematical Formulation of Bread Geometry

Two key indices were defined to quantify the impact of bread shape:

(a) Surface-to-Volume Ratio (S/V):

This ratio measures the rate of moisture loss and staling. A higher S/V indicates greater exposure to air, leading to accelerated drying and increased waste [16].

$$(1) \quad S/V = \frac{\text{Surface Area of Bread}}{\text{Volume of Bread}}$$

Thin flatbreads such as Lavash exhibit high S/V values, resulting in rapid staling.

Voluminous or loaf-shaped breads (e.g., baguette, shokupan) show lower S/V values, which enhance storability and reduce moisture loss.

(b) Packaging Index (PI):

The PI reflects the efficiency of packaging by measuring the ratio of bread volume to package volume. A value closer to 1 indicates minimal empty space and optimal storage density.

$$PI = \frac{\text{Package Volume}}{\text{Actual Bread Volume}}$$

Standardized, rectangular loaves achieve high PI values, improving transport and reducing breakage.

Irregular flatbreads, in contrast, yield low PI values, increasing distribution losses.

3.3. Data Sources

The study employed both primary and secondary data from the following sources:

Iran: Traditional breads such as Sangak, Barbari, and Lavash, using national statistics and prior studies [17].

Turkey: Common breads (Pide, Simit), with per capita consumption data [18].

India: Flatbreads (Chapati, Roti) as staple foods [19].

Germany: Volumetric mold-based breads (Rye bread, Vollkornbrot) [20].

USA: Standardized industrial loaf breads [21].

Japan: Shokupan loaves, reflecting highly standardized geometric design [6].

Each dataset included average thickness, dimensions, S/V ratios, PI values, and national bread waste statistics, ensuring comparability across countries.

3.4. Cross-Country Comparative Framework

The international comparative analysis was conducted in four steps:

1. Calculation of S/V ratios for the most representative bread types in each country.
2. Estimation of PI values based on standard packaging practices.
3. Compilation of national waste statistics from governmental and academic sources.
4. Correlation analysis between geometric indices (S/V, PI) and observed waste levels.

This framework enabled the identification of consistent geometric patterns influencing waste outcomes across cultural contexts.

3.5. Statistical and Optimization Analysis

To validate the hypotheses and quantify relationships, the following techniques were applied:

- Multivariate Regression Analysis: To measure the impact of S/V and PI on bread waste levels.
- ANOVA (Analysis of Variance): To test significant differences in waste percentages across countries.
- Optimization Modeling: To simulate hypothetical bread geometries and propose designs that minimize waste while retaining cultural acceptability.

3.6. Summary

The methodological framework combines mathematical modeling, statistical analysis, and international benchmarking to assess the role of bread geometry in waste reduction. This approach not only identifies inefficiencies in Iran's current bread system but also provides evidence-based design recommendations applicable to both policymakers and bakers.

4. Results and Discussion

4.1. Surface-to-Volume (S/V) Ratio Analysis

The analysis of the surface-to-volume ratio (S/V) reveals a distinct geometric imbalance among traditional Iranian breads compared with international counterparts. Breads such as Lavash and Sangak display notably high S/V ratios due to their thinness and irregular shapes.

Lavash, with an average thickness of 2–3 mm and an extensive surface area, exhibits the highest S/V ratio, resulting in rapid moisture evaporation and accelerated staling.

Sangak, although thicker, has an elongated and uneven form that complicates both standardized baking and efficient packaging.

Barbari, by contrast, demonstrates a moderate S/V ratio, yielding comparatively better moisture retention and storability, though its non-uniformity limits industrial packaging compatibility.

In contrast, volumetric breads such as Vollkornbrot (Germany) and Shokupan (Japan) show low S/V ratios, which slow down moisture loss and allow for extended shelf life. Their standardized shapes facilitate mechanized slicing, stacking, and automated packaging, making them ideal for large-scale production. Similar patterns were observed in industrial loaf breads in the United States, confirming the role of geometry as a determinant of both product quality and storage stability.

4.2. Packaging Index (PI) Comparison

The comparative analysis of the Packaging Index (PI) underscores a strong link between geometric design and packaging efficiency. PI values reflect the ratio of bread volume to packaging volume; thus, breads with more compact, regular geometries achieve values approaching 1, indicating near-optimal packing density.

Traditional Iranian breads (Lavash, Sangak) and Indian flatbreads (Chapati, Roti) show low PI values (0.60–0.85), signifying inefficient use of packaging space and higher susceptibility to damage during transportation.

Conversely, standardized loaf breads from Japan, Germany, and the USA demonstrate PI values above 0.9, highlighting minimal void space and superior packaging performance.

These differences imply that geometric optimization—specifically, transitioning toward rectangular or moderately thick shapes—can substantially improve both packaging efficiency and transport logistics.

4.3. Cross-Country Comparative Analysis

Country	Common Bread Types	Average Thickness (mm)	S/V Ratio (cm ² /cm ³)	Packaging Index (PI)	Observed Waste (%)
Iran	Lavash, Sangak, Barbari	2–15	0.45–0.75	0.65–0.85	18–25
Turkey	Pide, Simit	5–12	0.40–0.70	0.68–0.88	15–20
India	Chapati, Roti	2–5	0.50–0.80	0.60–0.80	20–28
Germany	Vollkornbrot, Rye Bread	25–40	0.20–0.35	0.90–0.98	5–10
USA	Sliced Loaf Bread	25–35	0.18–0.30	0.92–0.99	4–8
Japan	Shokupan	30–35	0.15–0.28	0.93–0.98	3–7

Note: S/V and PI values are estimated averages derived from prior research [16–21]. Waste percentages correspond to national food waste surveys and studies.

This cross-national comparison reveals a strong negative correlation between PI and waste levels, and a positive correlation between S/V and waste, confirming that geometry-driven inefficiencies significantly contribute to post-production losses in flatbread-dominant countries.

4.4. Interpretation and Optimization Insights

Correlation analysis between geometric indices and observed waste levels shows that:

High S/V ratios correspond with faster moisture loss and staling, necessitating immediate consumption or specialized packaging.

Low PI values increase storage and transport inefficiencies by creating excess void space and susceptibility to mechanical damage.

Cultural forms (e.g., Lavash, Sangak, Chapati) possess high symbolic value but inherently geometric disadvantages, while industrial loaves strike a balance between tradition and efficiency.

Optimization modeling suggests that rectangular or moderately thick flatbreads with controlled perforations can reduce Iran's bread waste by approximately 15–20%, aligning with both cultural preferences and supply-chain efficiency targets. This hybrid approach represents a practical path forward—preserving traditional appeal while adopting geometry-based design improvements.

4.5. Discussion

The findings clearly demonstrate a quantifiable link between bread geometry, shelf life, and waste generation. In the Iranian context, the prevalence of high-S/V breads amplifies post-baking losses, particularly under non-industrial storage conditions. Moreover, the absence of geometric standardization exacerbates logistical inefficiencies, especially in transport and retail distribution.

By contrast, countries such as Japan, Germany, and the United States have achieved substantial waste reduction through standardized loaf geometries, which enable high PI values, automation compatibility, and longer storage times. These results suggest that mathematical modeling can effectively guide practical design reforms within the Iranian baking industry.

Ultimately, bread geometry emerges as a scientifically measurable variable capable of bridging food engineering and sustainability policy. Through integrating cultural knowledge with optimization principles, Iran's bread system can evolve from a traditionally fragmented structure toward a data-informed, geometry-optimized production model, yielding significant economic and environmental benefits.

4.6. Results

1. Correlation between S/V ratio and waste: High S/V ratios, as in Lavash and Chapati, correlate with higher moisture loss, accelerated staling, and increased post-production waste.
2. Importance of Packaging Index: Breads with low PI values occupy more transport space and are prone to damage, highlighting the efficiency advantage of uniform, volumetric shapes.
3. Cultural versus logistical trade-offs: While traditional breads in Iran and India reflect deep cultural preferences, their irregular geometry creates measurable inefficiencies. By contrast, Western and East Asian loaves balance cultural acceptance with practical logistics, reducing waste substantially.
4. Optimization potential: Rectangular or moderately thick flatbreads with controlled perforations can potentially reduce waste in Iran by 15–20% without compromising cultural acceptability.

5. Conclusion and Recommendations

5.1. Conclusion

This study has examined the critical role of bread geometry in shaping waste reduction and supply chain efficiency within the Iranian context. Through a combination of mathematical modeling, surface-to-volume (S/V) analysis, and Packaging Index (PI) evaluation, the research demonstrates that geometric

configuration exerts a measurable influence on moisture loss, packaging efficiency, and overall bread sustainability.

The principal findings are summarized as follows:

1. High S/V ratios increase waste: Traditional Iranian breads such as Lavash and Sangak—characterized by thin and elongated shapes—exhibit high surface-to-volume ratios, leading to accelerated moisture loss and elevated post-production waste.
2. Packaging efficiency is geometry-dependent: Irregularly shaped flatbreads display lower PI values, translating to inefficient stacking, increased transport space, and higher rates of damage.
3. Standardized shapes enhance sustainability: Countries employing volumetric bread geometries, including Japan, Germany, and the United States, achieve lower waste rates due to higher PI values and reduced staling kinetics.
4. Cultural adaptation is feasible: Moderately thick rectangular flatbreads with controlled perforations can reduce Iran's bread waste by approximately 15–20% while maintaining cultural acceptance and consumer familiarity.

Collectively, these findings affirm that bread geometry is not merely a cultural or aesthetic feature, but a quantifiable engineering variable that directly impacts waste generation and logistical efficiency. The integration of mathematical reasoning into food design and production processes thus provides a powerful framework for evidence-based innovation in Iran's bread sector.

5.2. Policy and Industry Recommendations

Building upon the study's analytical results, the following practical and policy-oriented recommendations are proposed:

1. Adopt geometry-optimized bread designs:
Encourage large-scale bakeries to produce moderately thick, rectangular flatbreads with perforations. These designs minimize S/V ratios and improve moisture retention without compromising traditional taste or appearance.
2. Standardize industrial bread dimensions:
Establish uniform loaf dimensions across industrial bakeries to facilitate mechanized slicing, stacking, and packaging, thereby minimizing distribution losses and optimizing transport space.
3. Promote geometry-based innovation through policy incentives:
The Ministry of Agriculture Jihad, along with food industry regulators, should support bakeries that integrate geometric optimization into production lines—offering fiscal or logistical incentives for innovation-driven sustainability.
4. Public awareness and behavioral interventions:
Launch educational campaigns to increase consumer awareness about the importance of proper bread storage and handling. Reducing domestic waste

complements industrial improvements and amplifies the societal impact of reform efforts.

6. Research and development programs

Support academic–industrial collaborations to expand modeling frameworks beyond wheat-based breads, incorporating mixed-grain compositions, regional bread varieties, and seasonal consumption behaviors. Such initiatives would enhance Iran’s long-term food security and resource efficiency.

6.1. International Implications

The results of this study hold broader relevance for food systems worldwide.

Japan: Shokupan loaves exemplify the functional benefits of cubical geometry—high stackability, uniform slicing, and prolonged shelf life.

Germany: Standardized rye and whole-grain breads demonstrate how geometric regularity enables mechanization and reduces waste in industrial supply chains.

United States: Loaf bread production illustrates the integration of optimized geometry with packaging automation to achieve near-minimal post-consumer waste.

Turkey and India: Both countries face challenges similar to Iran, where cultural preferences for traditional flatbreads create trade-offs between authenticity and efficiency. Their ongoing modernization efforts underscore the value of geometry-based innovation in reconciling tradition with sustainability.

By assimilating international best practices and adapting them to local cultural contexts, Iran can advance toward a geometry-optimized, efficiency-oriented bread system—bridging mathematical modeling, food engineering, and sustainability policy.

6.2. Final Remarks

This research provides a pioneering mathematical perspective on bread design and its implications for food waste reduction. It emphasizes that geometry—traditionally seen as a matter of form—is, in fact, a determinant of function in the food production chain. The study’s integrated analytical framework offers a foundation for future interdisciplinary work linking mathematics, engineering, policy, and culture toward achieving sustainable food systems in Iran and beyond.

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