

# Low-Cost Process Interventions for Quality and Efficiency Improvement in Traditional Pita Bread Manufacturing

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## ABSTRACT

**Objective:** This study aims to optimize the artisanal production of pita bread in a small-scale bakery in Córdoba, Veracruz, Mexico, with the dual goal of enhancing product quality—particularly organoleptic attributes—and improving the thermal efficiency of the baking oven, thereby contributing to sustainable food processing practices.

**Design/methodology/approach:** A process engineering framework was applied to refine critical control points in dough preparation and baking. Key variables included fermentation time, kneading intensity, dough division, circular stretching, and high-temperature baking. Adjustments to formulation and processing parameters were evaluated for their impact on sensory properties. Oven design and thermal performance were also assessed. Blind sensory evaluations were conducted to validate improvements.

**Results:** Optimized fermentation and baking conditions yielded significant improvements in softness, moisture retention, and overall sensory acceptability. Enhanced oven performance contributed to greater consistency in bake quality and reduced batch-to-batch variability. The implementation of a standardized protocol improved operational efficiency and product uniformity, supporting the viability of artisanal methods within modernized frameworks.

**Limitations on study/implications:** While the study is confined to a single bakery, the methodological approach and findings are transferable to similar small-scale enterprises aiming to modernize traditional practices. The results underscore the potential for technology transfer and process standardization in preserving culinary heritage while advancing sustainability.

**Findings/conclusions:** Integrating process engineering with sensory analysis offers a robust strategy for improving artisanal pita bread production. This approach supports the development of resilient and sustainable food systems, particularly within small enterprises engaged in traditional food manufacturing.

**Keywords:** Artisanal bakery; pita bread; process optimization; sensory evaluation; thermal performance; sustainable food systems; technology transfer; traditional food preservation.

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## INTRODUCTION

Pita bread occupies a central role in Middle Eastern and Arab diets, serving not only as a staple carbohydrate source but also as a cultural and culinary emblem. Its versatility



enables its use as a vessel for dips such as hummus and baba ghanoush, a wrap for meats and vegetables, and a base for dishes like manakish and shawarma. The simplicity of its formulation—typically wheat flour, water, salt, yeast, and occasionally sugar—reflects the agrarian heritage of the region, where wheat cultivation has persisted for millennia (Guiné, 2022; Al Jawaldeh *et al.*, 2018).

The bread's distinctive pocket structure, formed through rapid steam expansion during high-temperature baking, facilitates its use in both communal and individual meals, aligning with traditional practices of hospitality and shared consumption (Waqar *et al.*, 2021). Nutritionally, pita bread provides essential carbohydrates, dietary fibre, and micronutrients such as iron and calcium, particularly when made with whole wheat flour (Al-Dmoor, 2012; Ranhotra *et al.*, 1984; USDA, 2022). Its clean-label formulation and excellent storage properties—maintaining freshness for up to five days at room temperature and up to one year when frozen—make it suitable for modern supply chains and regions with limited refrigeration infrastructure (Amr *et al.*, 2022).

This study investigates the rheological and sensory behaviour of pita dough during fermentation and baking, aiming to develop an optimized formulation that meets consumer expectations for softness, thinness, and flavour (Grafenauer *et al.*, 2020). The research also seeks to preserve artisanal quality by maintaining traditional wood-fired oven methods while enhancing economic viability for small-scale producers. By integrating process engineering with sensory evaluation, the study contributes to the modernization of traditional food systems and supports sustainable practices in artisanal bakery operations (Stone *et al.*, 2012).

The bakery under study, located in Córdoba, Veracruz, Mexico, has produced artisanal pita bread for over 65 years using a wood-fired oven, a method that imparts distinctive flavour and texture characteristics (Manhiça, 2014). The bread is distributed to surrounding cities including Fortín de las Flores, Orizaba, Río Blanco, and Camerino Z. Mendoza.

In recent years, the company has experienced a decline in sales. A distributor survey revealed consumer concerns regarding reduced softness and increased dryness, attributed to inconsistencies in dough formulation and baking conditions—particularly moisture retention and crust formation, which are critical to sensory appeal and bread staling (ShunGrill, 2024). In response, the company initiated a process optimization strategy targeting three areas: (1) dough reformulation to improve hydration and gluten development, (2) adjustment of fermentation and baking times to enhance texture and flavour, and (3) redesign of the wood-fired oven to improve thermal performance and consistency.

Sensory evaluation plays a pivotal role in guiding product development, with attributes such as crumb softness, aroma, mastication, and flavour influencing consumer satisfaction and market success (Callejo, 2011). By combining traditional baking techniques with contemporary sensory and technological insights, the company aims to revitalize its product offering and reinforce its position within the regional market, contributing to the broader goals of sustainable food systems and technology transfer for small enterprises (Contreras-Castro *et al.*, 2025).

## MATERIALS AND METHODS

### Materials

Four experimental formulations of pita bread dough were developed at laboratory scale using standard food-grade ingredients: wheat flour, water, yeast (dry or fresh), sugar, salt, and vegetable oil. Ingredient quantities for each formulation are detailed in Table 1. All components were weighed using a precision digital balance ( $\pm 0.01$  g accuracy) under controlled laboratory conditions to ensure reproducibility.

Baking trials were conducted using a custom-built artisanal wood-fired oven engineered to maintain uniform high-temperature conditions. The oven was constructed with thermally resistant materials selected for low thermal conductivity and high heat retention, including cement, steel rebar, river sand, glass, salt, refractory brick, fibreglass, and steel mesh.

### Dough Preparation

Each dough formulation followed a standardized preparation protocol. Formulation 1 served as the control, replicating the company's original recipe. Yeast activation was performed by dispersing dry or fresh yeast in warm water (27 °C) for 8-10 minutes. Formulation 1 used 12 g of dry yeast, while Formulations 2, 3, and 4 incorporated 15 g, 20 g, and 15 g of fresh yeast, respectively (Table 1).

Activated yeast was combined with remaining ingredients in a planetary mixer. Wheat flour ranged from 500 g to 550 g, water from 300 mL to 330 mL, sugar from 10 g to 50 g, salt from 5 g to 10 g, and vegetable oil from 0 mL to 37 mL. Dough was kneaded for 15-25 minutes until a homogenous, elastic consistency was achieved (Table 2).

### Fermentation and Shaping

Post-kneading, dough underwent bulk fermentation at ambient temperature for 30-40 minutes to facilitate gas development and gluten relaxation. Dough was then divided and manually rounded, followed by a bench rest of 10-15 minutes. Each portion was stretched into a 6 mm thick disc and rested for 8-15 minutes to promote puffing during baking. Process durations are summarized in Table 2.

**Table 1.** Ingredients and Cooking Parameters.

Dough	Formulation 1 (control)	Formulation 2	Formulation 3	Formulation 4
Wheat Flour (g)	514	530	500	550
Water (ml)	330	300	300	320
Yeast (g)	12 <sup>a</sup>	15 <sup>b</sup>	20 <sup>b</sup>	15 <sup>b</sup>
Sugar (g)	50	28	10	28
Salt (g)	5	10	10	10
Vegetable Oil (ml)	37	0	30	25

<sup>a</sup> dry yeast, <sup>b</sup> fresh yeast.

**Table 2.** Process stages time (min) per formulation.

Process Stage	Formulation 1 (control)	Formulation 2	Formulation 3	Formulation 4
Yeast activation time (at 27 °C)	8-10	8-10	8-10	8-10
Kneading Time	15-25	15-25	15-25	15-25
First bulk fermentation time	30-40	30-40	30-40	30-40
Splitting and rounding time	10-15	10-15	10-15	10-15
Bench Rest	10-15	10-15	10-15	10-15
Stretching Time	4-6	4-6	4-6	4-6
Final fermentation rest	8-15	8-15	8-15	8-15

### Baking Procedure

Each formulation was baked in both the traditional and optimized wood-fired ovens, with three rounds of baking per formulation (each round consisting of four loaves), resulting in 12 loaves per formulation and a total of 48 loaves per oven. Across both ovens, 96 loaves were produced. Both ovens were preheated for two hours to ensure full thermal saturation. After preheating, embers were removed and the hearth was cleaned using a moistened brush. The baking temperature was maintained for the Traditional Oven to thermal sensation (according to the experience of the Company workers) and at 195 °C for the Optimized Oven, as verified by an infrared thermometer.

Pitas were loaded into the oven using a long-handled peel and baked according to appearance-based timing. In the traditional oven, baking times were 10 minutes for Formulation 1 (control), 14 minutes for Formulations 2 and 3, and 15 minutes for Formulation 4. In contrast, the optimized oven required shorter baking durations: 7 minutes for Formulation 1 (control), 10 minutes for Formulation 2, 11 minutes for Formulation 3, and 12 minutes for Formulation 4. These comparative baking times are summarized in Table 3. The thermal design of the optimized oven facilitated rapid and uniform baking while reducing fuel consumption.

### Post-Baking Handling

Immediately after baking, loaves were stacked in covered containers to retain moisture and prevent crust hardening. Once cooled, samples were packaged in food-grade polyethylene bags for subsequent analysis.

**Table 3.** Comparative average baking times (minutes) for each formulation (12 loaves) using the traditional and optimized ovens.

Formulation	Traditional Oven (time, min)	Optimized Oven (time, min)
1 (control)	10	7
2	14	10
3	14	11
4	15	12

## **Blind and Quantitative Sensory Evaluation Methodology for Pita Bread**

### **Experimental Design**

Sensory evaluation employed a blind, monadic sequential, within-subject design to assess consumer acceptance across eight pita bread formulations. This method minimizes bias and supports robust comparative analysis (Stone *et al.*, 2020).

### **Participants and Setting**

Ninety-six untrained consumers were recruited, all regular bakery product users. Evaluations were conducted in individual booths under standardized ambient conditions to prevent interaction and sensory interference (Callejo, 2011).

### **Sample Preparation and Presentation**

Samples were coded with random three-digit alphanumeric labels and served at uniform temperature. Presentation order was randomized, and palate cleansers (water and unsalted crackers) were provided between samples, with 30-second rest intervals to reduce sensory fatigue.

### **Instrument and Evaluation**

Participants used an eight-point hedonic scale (1=least favourable, 8=most favourable) to evaluate four attributes: texture (chewiness and cohesion), flavour, softness, and cavity formation. Total acceptance scores were calculated by summing attribute scores.

### **Data Analysis**

Evaluation data were transcribed into a spreadsheet matrix (96 rows  $\times$  8 columns), subdivided by attribute and total score. Descriptive statistics (mean, standard deviation) were computed for each formulation following ISO 8589:2010 and Stone *et al.* (2020).

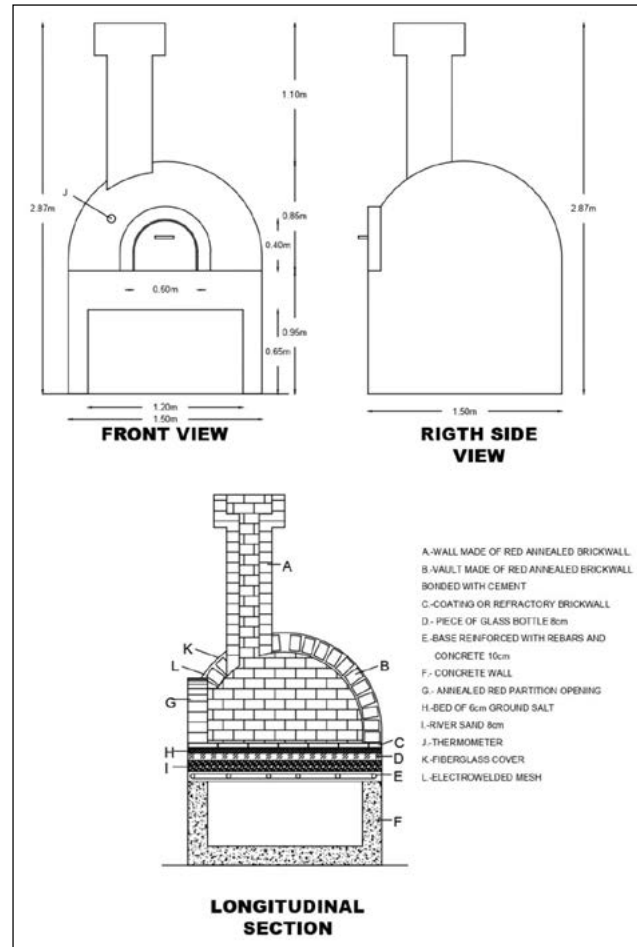
This protocol ensured unbiased, rigorous comparison of pita bread formulations, supporting the development of improved products in artisanal bakery contexts.

## **RESULTS AND DISCUSSION**

### **Artisanal Wood-Fired Oven Design for Pita Bread Baking**

Optimal baking of pita bread requires uniform heat distribution and sustained high-temperature exposure to achieve proper puffing and pocket formation (Manhiça, 2014; Kosemani *et al.*, 2021). To meet these requirements using wood as the primary fuel source, a specialized oven was designed incorporating materials selected for their thermal conductivity, heat capacity, and resistance. Figure 1 illustrates the structural configuration, including a reinforced base and a dome sealed with fibreglass and steel mesh to enhance insulation and durability.

Table 4 summarizes the thermal properties of the materials employed. Low-conductivity components such as cement, river sand, and fibreglass act as insulators, while refractory brick and glass contribute to heat retention. This combination ensures thermal stability and minimizes heat loss during baking.



**Figure 1.** Oven design for optimal pita bread baking.

**Table 4.** Thermal properties of the oven materials.

Material	Thermal Conductivity (W/m·K)	Specific Heat Capacity (kJ/kg·K)	Thermal Resistance (°C)
Cement	0.29	0.88	1000
Steel Rebar	50.20	0.49	1500
River Sand	0.25	0.80	1700
Glass	1.05	0.84	1200
Salt	6.00	0.86	800
Refractory Brick	1.30	1.00	1600
Fibreglass	0.04	0.84	500
Steel Mesh	50.20	0.49	1500

### Thermal Analysis of the Oven

The thermal performance of the proposed oven is a critical determinant of baking quality and operational efficiency. The multilayered structure —comprising insulating and heat-retaining materials— was designed to optimize heat transfer dynamics while minimizing

fuel consumption. Materials such as cement, river sand, and fibreglass exhibit low thermal conductivity (0.04–0.29 W/m·K), functioning as effective insulators that reduce conductive heat loss. Conversely, refractory brick and glass, with higher thermal conductivity and specific heat capacity, serve as thermal reservoirs, ensuring prolonged heat retention and stability during baking cycles (Table 4).

This configuration promotes uniform heat distribution across the hearth and dome, mitigating the common issue of localized overheating observed in traditional wood-fired ovens. By maintaining a consistent baking temperature of approximately 195 °C, the oven facilitates rapid steam generation within the dough, enabling proper pocket formation—a defining characteristic of pita bread. The thermal inertia provided by the composite structure reduces temperature fluctuations, thereby improving batch-to-batch consistency and sensory quality.

From an energy perspective, the oven demonstrates improved fuel efficiency compared to conventional designs. The enhanced insulation reduces wood consumption by limiting heat dissipation, aligning with sustainability objectives for small-scale enterprises. These findings are consistent with established principles of heat transfer—conduction through solid layers, convection within the oven chamber, and radiative heat from the dome surface—as described by Incropera and DeWitt (2002). Furthermore, the design incorporates best practices identified in energy-efficient cooking technologies (Sharma *et al.*, 2021), emphasizing the integration of locally available materials to reduce costs and environmental impact.

When benchmarked against gas and electric ovens, the proposed design offers a unique balance: it preserves the artisanal characteristics imparted by wood-fired baking while achieving thermal efficiency comparable to modern systems. Unlike gas ovens, which rely on non-renewable energy, or electric ovens, which may fail to reach the high temperatures required for pita baking, this oven leverages renewable biomass and advanced insulation to meet both cultural and technical requirements.

Future research should include quantitative thermal mapping using infrared thermography to validate heat distribution patterns, as well as life-cycle assessments to evaluate environmental benefits relative to conventional ovens. Additionally, field trials in diverse geographic regions could confirm adaptability and scalability, supporting technology transfer to other artisanal bakery contexts.

### **Dough Characteristics and Baking Performance**

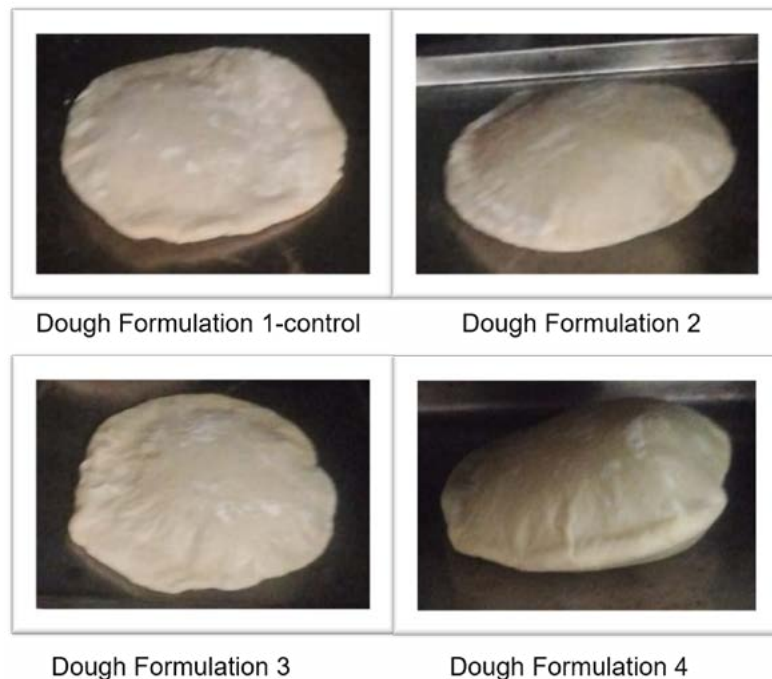
The four experimental formulations exhibited distinct rheological and sensory behaviours during baking, reflecting the influence of ingredient composition and fermentation dynamics:

- Formulation 1 (Control): Produced a compact structure lacking the characteristic internal pocket of pita bread. The absence of puffing suggests inadequate fermentation or insufficient gluten development, resulting in poor oven spring and limited consumer appeal.

- Formulation 2: Achieved proper pocket formation and rapid baking response. However, sensory evaluation indicated an excessively salty flavour, which negatively impacts palatability and market acceptance despite favourable textural attributes.
- Formulation 3: Demonstrated successful pocket formation and efficient baking performance. Nevertheless, its reduced sugar content yielded a less desirable flavour profile, lacking the mild sweetness traditionally associated with pita bread.
- Formulation 4: Identified as the optimal formulation, exhibiting excellent puffing, uniform cavity development, and a soft, moist crumb. Sensory analysis confirmed a balanced flavour profile and high consumer acceptability. This formulation performed consistently in both wood-fired and gas ovens, underscoring its versatility for artisanal and semi-industrial applications.

Visual comparisons of baking performance in the optimized oven (Figure 2) highlight the superior puffing and cavity formation achieved by Formulations 2, 3, and 4 compared to the control. Figure 3 further illustrates the internal structure of Formulation 4, confirming proper fermentation and thermal conditions conducive to pocket development.

These findings emphasize the critical role of ingredient ratios—particularly yeast, sugar, and hydration—in determining dough rheology and final product quality. Optimizing these parameters enhances sensory appeal while maintaining alignment with traditional pita characteristics.



**Figure 2.** Visual comparison of the final baked products obtained from the four distinct dough formulations, highlighting differences in puffing, texture, and internal pocket formation baked in the optimized oven.



**Figure 3.** Optimal pita bread product (Formulation 4) displaying a well-developed internal cavity, indicative of proper fermentation and baking conditions.

### Preparation Time Analysis

Total preparation times varied across formulations, ranging from 96 to 120 minutes (Table 5). Formulation 4 required the shortest time (96 minutes), attributed to efficient fermentation and dough handling properties, whereas Formulation 1-control exhibited the longest duration (120 minutes), reflecting less favourable dough extensibility and fermentation kinetics.

All formulations were baked at a consistent temperature of 195 °C for 7-12 minutes, with hydration levels maintained at approximately 60-65%. These parameters contributed to optimal textural properties in Formulation 4, confirming its status as the most efficient and sensory-preferred option. Formulation 2 ranked second in overall performance, despite its excessive salt content, indicating that minor adjustments could further improve its acceptability.

The reduction in preparation time for Formulation 4 has practical implications for small-scale bakeries, enabling increased throughput and operational efficiency without compromising product authenticity. This aligns with the broader objectives of sustainable food systems and technology transfer, supporting artisanal enterprises in adopting standardized, resource-efficient practices.

### Comparison of Ovens efficiency

The comparative performance of the traditional company oven and the optimized wood-fired oven is summarized in Table 6, based on the production of 48 pita loaves (12 pieces per formulation, baked in three batches of four pieces each).

**Table 5.** Total Average Preparation Time.

Formulation	Average Time
1	120 min
2	110 min
3	113min
4	96 min

**Table 6.** Comparative performance of the traditional and optimized ovens.

Parameter	Traditional Oven	Optimized Oven
Wood Consumption during Preheating (2 hours)	6 kg	4.8 kg
Temperature Achieved during Preheating	Thermal sensation	195°C
Preheating Time to Reach Target Temperature	90 min	60 min
Wood Consumption for Total Production of 48 Pieces	7 kg	5.6 kg

The optimized oven demonstrated superior thermal performance and resource efficiency across all measured parameters. Preheating time was reduced by 33%, from 90 minutes to 60 minutes, enabling faster operational readiness. Wood consumption during preheating decreased by 20%, and total fuel usage for the complete production cycle was reduced by approximately 1.4 kg, representing a 20% improvement in energy efficiency.

Achieving a stable baking temperature of 195 °C in the optimized oven ensured consistent product quality while minimizing thermal fluctuations. This improvement is attributed to the oven's multilayered insulation system, which enhances heat retention and reduces conductive losses. In contrast, the traditional oven relied on subjective thermal assessment ("thermal sensation"), introducing variability in baking conditions and increasing the risk of inconsistent product outcomes.

From a sustainability perspective, reduced wood consumption translates into lower greenhouse gas emissions and cost savings for small-scale enterprises. These findings align with global efforts to promote energy-efficient cooking technologies in artisanal food systems (Sharma *et al.*, 2021; Patel *et al.*, 2019). Furthermore, the shortened preheating time improves production throughput, supporting economic viability without compromising the authenticity of wood-fired baking.

Future work should include a detailed life-cycle analysis to quantify environmental benefits and explore the integration of renewable biomass sources to further enhance sustainability. Additionally, thermal mapping and computational fluid dynamics (CFD) simulations could provide deeper insights into heat distribution patterns, informing further design refinements.

### Sensory evaluation

The sensory evaluation results confirm that consumer preferences are strongly influenced by dough characteristics—particularly softness, cavity formation, and overall texture. These attributes are critical determinants of product acceptability and market success, consistent with prior research emphasizing the role of crumb structure and moisture retention in flatbreads (Stone *et al.*, 2020; Callejo, 2011). The optimized oven design significantly contributed to achieving these desirable qualities by enabling faster and more efficient baking cycles, which minimized moisture loss and preserved dough elasticity. This effect was especially pronounced in formulations with higher hydration levels, where excessive drying typically compromises texture and flavour.

Uniform heat distribution in the optimized oven reduced variability between batches, ensuring consistent pocket formation—a hallmark of authentic pita bread. These findings underscore the synergistic impact of process optimization and equipment design in enhancing organoleptic properties while maintaining traditional baking methods. Importantly, the results demonstrate that technological interventions, when carefully integrated, can elevate artisanal production without sacrificing authenticity, offering a viable pathway for small-scale bakeries to improve competitiveness and consumer satisfaction.

### Sensory Evaluation Protocol

For each dough type, twelve pita breads were produced and cut into eight portions, yielding 96 samples per formulation. Ninety-six untrained consumers participated, each evaluating eight samples (one from each dough type) under blind conditions. Attributes assessed included texture, flavour, softness, and cavity formation using an 8-point hedonic scale (1=least favourable; 8=most favourable). Definitions of attributes were provided to ensure consistency:

- a) Texture: Mouthfeel during mastication (cohesion, chewiness, granularity).
- b) Flavour: Overall taste perception (saltiness, sweetness, yeast notes).
- c) Softness: Resistance to compression and tenderness to touch and bite.
- d) Cavity: Size, uniformity, and ease of opening of the internal pocket.

### Global Acceptance Summary

Table 7 presents mean acceptance scores and standard deviations for the four formulations under two baking conditions: conventional oven and optimized oven.

Formulation 4 achieved the highest overall acceptance under both conditions, peaking at  $7.81 \pm 0.44$  in the optimized oven. Formulations 2 and 3 also improved significantly when baked in the optimized oven, increasing by 0.66 and 0.77 points, respectively. Conversely, Formulation 1 exhibited a decline in acceptance when baked in the optimized oven, suggesting a negative interaction between its composition and the accelerated thermal process—possibly due to overcooking or amplification of pre-existing sensory defects such as dryness or inadequate cavity formation.

Low standard deviations (0.41-0.54) across all samples indicate consistent responses among participants, reinforcing the reliability of the findings.

**Table 7.** Acceptance scores and standard deviations.

Dough Type	Traditional Oven	Optimized Oven
Formulation 1 (control)	$4.57 \pm 0.49$	$3.29 \pm 0.53$
Formulation 2	$5.40 \pm 0.53$	$6.06 \pm 0.52$
Formulation 3	$4.32 \pm 0.41$	$5.09 \pm 0.54$
Formulation 4	$6.09 \pm 0.45$	$7.81 \pm 0.44$

### Impact of Formulation and Baking Process

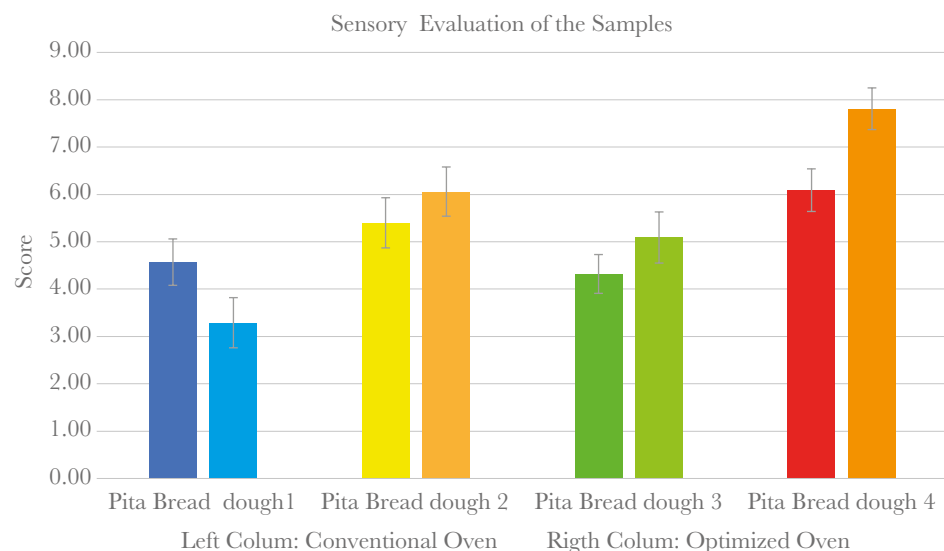
The comparative analysis highlights that both dough formulation and baking technology are critical determinants of consumer acceptance (Figure 4). The optimized oven exerted a net positive effect on most formulations, likely due to improved heat distribution and reduced moisture loss, which enhance softness, cavity formation, and flavour development through Maillard reactions. The superior performance of Formulation 4 under optimized conditions underscores its market potential, combining high acceptance scores with low variability —attributes essential for commercial success.

In contrast, the decline observed in Formulation 1 emphasizes that process optimization is not universally beneficial; formulation-specific adjustments to baking parameters are necessary to avoid adverse outcomes. Overall, the pairing of Formulation 4 with the optimized oven represents the most promising strategy for product differentiation and competitive advantage in artisanal pita bread production.

The technological advantage of the optimized oven lies in its multilayer insulation and superior heat retention, which mitigate the limitations of traditional ovens —such as excessive fuel consumption, extended baking times, and accelerated moisture evaporation. By preserving internal hydration and ensuring uniform thermal distribution, the optimized design enhances textural quality and cavity formation, reinforcing the role of process engineering in elevating sensory attributes without compromising authenticity.

### Productivity Improvement

One of the most significant outcomes of the process and equipment optimization was the marked improvement in production capacity and market performance. The enhanced sensory quality of the product —particularly softness, cavity formation, and flavour balance— resulted in increased consumer acceptance among new customers and the recovery of previous clientele. This improvement translated into a substantial rise in daily



**Figure 4.** Comparison of Texture, Flavor, Smoothness and Cavity for the products from both Ovens.

production, from 950 pieces to approximately 1,510 pieces, representing a 59% increase in output for the artisanal bakery located in Córdoba, Veracruz.

From an economic perspective, this productivity gain directly impacted revenue generation. Prior to optimization, daily sales averaged \$4,750 MXN, based on packages of five pieces sold at \$25 MXN per package using the traditional oven. Following implementation of the optimized process and oven design, daily sales increased to \$7,552 MXN, corresponding to the production of 302 packages per day. This represents a significant improvement in operational efficiency and profitability, achieved without compromising the authenticity of the product or the artisanal nature of the baking process.

The observed increase in productivity and revenue underscores the potential of process engineering interventions to strengthen the economic resilience of small-scale bakeries. By reducing preparation time, improving oven efficiency, and enhancing product quality, these technological adjustments enable artisanal enterprises to compete more effectively in regional markets while maintaining cultural and culinary heritage. Furthermore, the integration of sustainable practices—such as reduced fuel consumption and standardized protocols—aligns with broader objectives of resource efficiency and environmental stewardship.

Future research should explore cost-benefit analyses and scalability assessments to determine the feasibility of replicating this model in other artisanal bakery contexts. Additionally, longitudinal studies on consumer loyalty and market expansion could provide insights into the long-term economic impact of such interventions.

## CONCLUSIONS

This study demonstrates that systematic process optimization in artisanal pita bread production can significantly enhance both product quality and operational efficiency. By refining critical control points—including dough formulation, fermentation time, kneading intensity, and baking conditions—measurable improvements were achieved in texture, moisture retention, and sensory acceptability. These findings confirm the value of integrating traditional baking practices with modern process engineering principles.

The introduction of a thermally efficient wood-fired oven, constructed using materials selected for low thermal conductivity and high heat retention, contributed to uniform heat distribution, reduced fuel consumption, and improved baking consistency. Among the four formulations tested, Formulation 4 emerged as the optimal variant, exhibiting superior softness, cavity formation, and flavour balance. Its reduced preparation time (96 minutes) and adaptability to both wood-fired and gas ovens further support its suitability for artisanal and semi-industrial applications.

Sensory evaluation confirmed that both dough formulation and baking technology are critical determinants of consumer acceptance. Formulation 4 achieved the highest acceptance score ( $7.81 \pm 0.44$ ) when baked in the optimized oven, indicating strong and consistent consumer preference under improved thermal conditions. Formulations 2 and 3 also benefited from optimized baking, while Formulation 1 exhibited a decline in acceptance, underscoring the need for formulation-specific adjustments to avoid undesirable outcomes.

Overall, these results highlight the importance of aligning formulation development with tailored baking parameters to maximize product quality. The combination of Formulation 4 and the optimized oven design represent the most promising strategy for achieving high consumer satisfaction and market competitiveness in artisanal pita bread production. Furthermore, this research underscores the potential of combining traditional baking methods with process engineering and sensory evaluation to modernize artisanal food systems without compromising authenticity.

Although the study was conducted in a single bakery, the methodology and insights are transferable to similar small-scale operations seeking to improve product consistency, resource efficiency, and consumer acceptance. Future work should focus on scalability assessments, life-cycle analysis of environmental impacts, and the integration of renewable biomass sources to further enhance sustainability. These efforts will support technology transfer and strengthen the resilience of traditional food systems within the framework of sustainable development.

### Supplementary Material

CAD files of the oven and Instrument for Sensory Evaluation are available upon request.

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