PREMIO NACIONAL JUVENIL DEL AGUA 2025

STOCKHOLM JUNIOR WATER PRIZE

Entry to the Stockholm Junior Water Prize 2025

NixtaFlow: Sustainable Water Use in Tortilla Production

Pablo Alejandro Olivares Ramírez

Maximo Emiliano Estrella Suárez

MEXICO

Embajada de Suecia Ciudad de México

Sponsors:

TABLE OF CONTENTS

System for reusing waste water generated during tortilla production

Abstract

This study presents the development of a process for the treatment and reuse of nejayote, a liquid waste generated during nixtamalization—an ancestral Mesoamerican technique in which maize is cooked in an alkaline solution to produce dough, the basis of tortillas. While essential to traditional diets, this technique produces a highly polluting byproduct characterized by a high organic load, suspended solids, and an alkaline pH. Commonly discarded without prior treatment, nejayote contributes significantly to environmental degradation.

The primary objective of this project is to enhance water-use efficiency, reduce contamination of water resources, and promote sustainable practices among small- and medium-scale tortilla producers. To this end, a mechanical sedimentation treatment system was designed that operates without electricity and enables the separation of solids and clarification of the liquid within a 90-minute cycle. The treated liquid can be reused up to three times within the same production process, significantly reducing overall water consumption. Additionally, the recovered solids can be reincorporated into the maize dough without altering its organoleptic properties, further improving the efficiency of the system. The proposal also includes the creation of an environmental label for tortilla shops that implement the system, allowing customers to identify businesses with sustainable practices and enabling producers to enhance their public image.

The proposal was developed through a comprehensive approach that included literature review, technical design, and experimental validation. Physicochemical analyses, sensory evaluations, and acceptance surveys confirmed the technical, economic, and environmental viability of the system. At both local and regional levels, the prototype represents a replicable solution that promotes resource recovery, reduces pollutant discharges into wastewater systems, and lowers water use, generating direct benefits for both producers and the environment.

In addition to providing a practical solution to a widespread challenge in the traditional maize industry, this approach aligns with the principles of the 2030 Agenda for Sustainable Development by integrating technical innovation, environmental responsibility, and social equity into a viable, accessible, and scalable solution—both in Mexico and internationally in nixtamalization processes or similar operations.

Abbreviations and acronyms used

NOM: Mexican Official Standard

SEMARNAT: Ministry of the Environment and Natural Resources (Mexico)

SIAPA: Intermunicipal System for Potable Water and Sewerage Services

SDGs: Sustainable Development Goals

Acknowledgements

We would like to express our sincere gratitude to our advisor, Araceli de Jesús Alcaraz Salcedo, for her valuable guidance, patience, and commitment throughout the development of this project. Her support was essential in shaping our ideas and carrying them out in a structured and professional manner.

We also extend our thanks to our teammate, Arely Narumy Lozano Jiménez, for her dedication, creativity, and continuous effort, which were fundamental to the construction and strengthening of each stage of the project.

We are deeply grateful to our families for their unconditional support, motivation, and trust throughout this endeavor.

In particular, we would like to acknowledge Santiago Suárez Arana for his assistance in helping us understand the nixtamalization process, and Melquiades Olivares Juárez for his collaboration in the development of the prototype.

We also express our appreciation to the Centro de Enseñanza Técnica Industrial (CETI), especially to its director, Óscar Sandoval, for the support provided during this formative stage.

Objectives

General Objective:

To develop a solution for the treatment of nejayote, the liquid waste generated during the nixtamalization process used to produce tortillas, with the aim of: (1) reducing water consumption in tortilla production; (2) enabling the reuse of water across various stages of the production process; (3) decreasing pollution in water bodies by preventing the discharge of untreated nejayote into the sewage system; and (4) encouraging more responsible consumer behavior in the tortilla industry.

Specific Objectives:

- To reduce water consumption in tortilla shops through the implementation of the treatment device.

- To analyze the potential for reincorporating the separated solids into the dough and tortillas in order to enhance productivity and nutritional value, thereby increasing producers' willingness to adopt the device in their production processes.

- To evaluate the operational feasibility of the device, ensuring that the system is easy to implement and efficient in managing the waste it treats.

- To develop an environmental label for small- and medium-scale tortilla producers who adopt the device, in order to encourage more responsible consumer behavior.

Problem statement

Since ancient times, maize has represented much more than just a crop in the region now known as Mexico—it has symbolized life, identity, and a deep connection with the land. Mesoamerican civilizations, which extended far beyond present-day Mexico to cover much of the American continent, not only domesticated maize thousands of years ago, but also revered it as a sacred food, central to their worldview and existence. For cultures such as the Maya and the Aztecs, this reverence is reflected in foundational myths like the Popol Vuh, where the gods create humankind from maize dough, imbuing it with body, soul, and purpose.

This profound relationship between food and culture endures today, with the tortilla standing as one of the most iconic pre-Hispanic legacies. Made from maize through the nixtamalization process (from the Nahuatl words nextli, meaning "lime ashes," and tamalli, meaning "maize dough"), the tortilla remains a staple food and a living cultural heritage on millions of Mexican tables. Today, maize continues to be the most important agricultural crop in Mexico, with an annual production exceeding 22 million tons (SIAP-SAGARPA, 2015). Per capita tortilla consumption in Mexico is estimated at 120 kilograms per year (Ochoa & Viniegra, 2009), making it the second most important item in the national basic food basket.

Nixtamalization involves cooking maize in a mixture of water and calcium hydroxide (lime). This process softens the kernels, removes the pericarp, and releases nutrients, resulting in nixtamal, the base for tortilla dough. However, it also generates a liquid byproduct known as nejayote (Antunes-Gutiérrez, 2022), the management of which presents a significant environmental challenge.

In Mexico, it is estimated that approximately 135,000 tortilla shops produce over 22 million cubic meters of nejayote annually (Díaz-Vega, 2022). This waste is characterized by a high organic load (2,984.10 mg/L of total organic carbon), an extremely high chemical oxygen demand (40,058.14 mgO_2/L), elevated suspended solids (11,680 mg/L), high hardness (5,768.67 mg/L), and an alkaline pH ranging from 10 to 14 (Castro-Muñoz, 2017). These characteristics make nejayote a potentially hazardous industrial effluent.

Improper discharge of nejayote into surface water bodies or urban sewage systems contributes to water pollution, lowers dissolved oxygen levels, harms aquatic biodiversity, and accelerates eutrophication. Its high nutrient content also promotes the growth of microorganisms and foul odors, representing a serious environmental risk (Soto-Cruz, 2011). Paradoxically, despite its rich composition in nutrients and organic matter, this byproduct is often discarded without treatment, in a national context already marked by water scarcity.

From a social perspective, the lack of accessible technologies for treating nejayote perpetuates unsustainable practices in the tortilla industry, particularly among small and medium producers. This is compounded by limited awareness of the long-term environmental impacts of improper waste management and the absence of practical tools to address the issue.

In response to this problem, the project proposes the design of a mechanical treatment device capable of separating solids and liquids in nejayote, reducing its organic load, and enabling water reuse within the same production cycle. Additionally, the recovered solids can be reintegrated into the maize dough to enhance its nutritional value, close production loops, and promote a circular economy model.

This project aims not only to reduce the environmental impact of nejayote, but also to strengthen the sustainability of the tortilla industry by: (1) increasing producers' profitability through the reuse of materials and the reduction of water and electricity costs; (2) enhancing the nutritional profile of tortillas through the reintegration of nejayote into the production process; (3) encouraging more responsible consumption via an environmental label for tortilla shops adopting the device; and (4) preserving a culinary heritage that is central to Mexican identity and that holds potential applications in similar processes worldwide.

Methodology

Planning

Diagram 1. Methodological stages of the project. Own elaboration 03/01/2025

A literature review was initially conducted to understand the characteristics of nejayote. This information was essential for designing appropriate treatment strategies.

Table 1. Physicochemical properties of untreated nejayote.
Values represent typical concentrations as observed in laboratory samples.
Adapted from Díaz-Montes et al. (2016).

Properties	Parameter
Total solids content (g·L-1)	11.68
Total soluble solids (°Brix)	1.53
Total organic carbon (mg·L-1)	2,984.10
Chemical oxygen demand (COD) (mg·L-1)	25,000 – 30,000
Total polyphenols (mg gallic acid·L-1)	1,190
pH	12 - 14
Density (kg·m-3)	1,003.54
Viscosity (Pa-s)	0.002301
Nitrogen-Free extract (ppm)	200 - 300
Calcium (mg·L-1)	1,526.21
Moisture (%)	97.72
Ashes (%)	0.0767
Crude Protein (%)	7.42
Crude fat (%)	1.48
Crude fiber (%)	19.3
Carbohydrates (%)	0.862

The proposed system addresses the technical challenges related to the disposal of nejayote, which in its untreated state fails to meet the standards established by Mexican regulations for wastewater disposal, as well as those of the European Union—Directive 91/271/EEC—governing the treatment of urban wastewater.

Criteria of the proposed system:

- Process up to 30 liters per cycle.
- Maximum sedimentation time of 90 minutes.
- Remove at least 90% of the suspended solids.
- Enable reuse of the clarified liquid, reducing overall water consumption.
- Utilize materials resistant to the alkalinity of the waste.

Operating principle:

The system operates based on gravity-driven sedimentation within a conical-bottom tank. In this configuration, solids settle at the bottom and can be easily extracted through valves, without the need for electrical equipment. The separated solids may be reincorporated into the maize dough to enhance its nutritional content, while the clarified liquid can be reused in subsequent nixtamalization cycles.

Design:

- Prototype Components and Materials:

Main Container:

- Material: Stainless steel (depending on budget and operational conditions).
- Shape: Cylindrical with a conical base to facilitate solid sedimentation.
- Capacity: 30 liters (adjustable to 50 or 80 liters based on the nejayote volume generated by the facility).

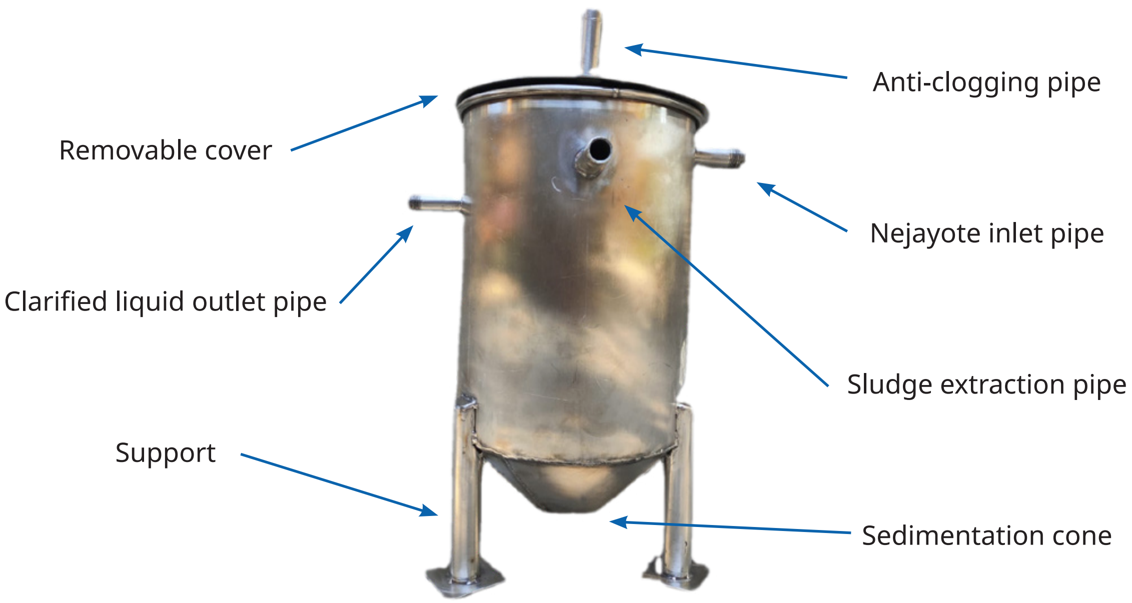

Figure 1. Separation device. Own photograph, 11/26/2024.

Valve System:

- Inlet Valve for Raw Nejayote (1-inch diameter):
  - Located at the top of the prototype.
  - Connected to a pipe system that can be directly linked to nixtamalization

vessels or used manually through a removable cover for pouring in nejayote.

- If the valve connection is used, it includes an internal disk to prevent settled solids from being disturbed when new flow enters.

○ Sludge Extraction Valve (3/4-inch diameter):

- Located near the top of the device, slightly below the inlet valve.
- Connected to an internal pipe that reaches the lowest point of the conical base to ensure efficient removal of settled solids.
- Includes a vertical external pipe that can be unclogged easily using a rod.

○ Clarified Liquid Outlet Valve (3/4-inch diameter):

- Located on the side, slightly lower than the sludge extraction valve.
- Designed to discharge the clarified liquid

Figure 2. Device with valves. Own photograph, 01/21/2025.

Pipes and Accessories:

○ Material: Corrosion-resistant stainless steel suitable for alkaline environments.

○ Diameters: Appropriate for the estimated nejayote flow (2–3 cm).

○ High-density polyethylene container for collecting and storing solids for reuse.

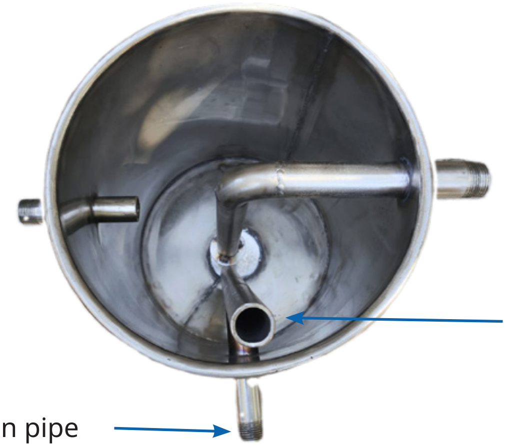

Figure 3. Internal piping of the prototype. Own photograph, 11/26/2024.

Execution

Operation Procedure:

1. Loading the raw *nejayote*:

- Connect the nixtamalization container to the upper valve, or remove the top lid to pour the nejayote manually.
- The flow is directed to the bottom of the vessel through an internal pipe, minimizing disturbance of already-settled solids.

Figure 4. Nejayote loading into the device. Own photograph, 01/19/2025.

2. Sedimentation:

- Allow the mixture to rest for 90 minutes so that suspended solids settle in the conical base.
- Visually monitor the process until the clarified liquid becomes visible.

The following image exemplifies the sedimentation phases of *nejayote*.

Figure 5. Nejayote phases in a decantation pear. Own photograph, 01/17/2025.

3. Sludge extraction:

- Open the lower valve to carefully extract the accumulated solids.
- If blockage occurs, use the external vertical pipe to clear the obstruction.
- Extracted solids can be:
    - Reincorporated into the dough at a ratio of 70 g per 1 kg of dough, enriching the calcium content without altering taste or texture.
    - They can also be repurposed for other industries with less economic value such as: poultry feed, livestock supplements or raw material for organic fertilizers

Figure 6. Nejayote in the device ready for extraction. Own photograph, 01/19/2025.

4. Extraction and recirculation of clarified liquid:

Once solids have settled:

- Open the middle side valve to extract only the clarified liquid.
- This liquid can be recirculated up to two additional times in subsequent nixtamalization processes, as follows:
- Day 1: Nejayote is generated and clarified liquid is extracted.
- Day 2: The clarified liquid is reused for a new cooking cycle, and the process is repeated.
- Day 3: The liquid is recirculated one final time, optimizing the use of water and lime.

Figure 7. Nixtamalization kettle with nejayote recirculation.
Own photograph, 01/15/2025.

5. Complementary Stage: Neutralization of Clarified Liquid

If the clarified liquid is to be discarded after the third recirculation cycle, a neutralization process may be applied to meet the pH limits established by the Mexican Official Standard for wastewater disposal.

Procedure:

1. Slowly add “Neutrayote”, a neutralizing solution specifically formulated to reduce nejayote alkalinity developed by other students.

2. Observe the color change to pink (indicating residual alkalinity).

3. Continue adding until a pale-yellow color appears, indicating neutrality.

4. Safely dispose of the liquid in compliance with applicable environmental regulations.

Figure 8. Neutralizing solution “Neutrayote”. Own photograph, 11/19/2024.

Figure 9. Example of nejayote color changes during the process.
Own photograph, 11/19/2024.

Evaluation

1. Quantitative, qualitative, and experimental methods:

    - Measurement of settleable solids using an Imhoff cone:

A 1-liter sample of nejayote was poured into an Imhoff cone for one hour. The sedimentation line was then recorded and analyzed.

Figure 10. Nejayote in an Imhoff cone. Own photograph, 01/21/2025.

- Calcium determination:

Tests were conducted to evaluate the system's efficiency and to determine calcium content in enriched tortillas. The procedure was adapted from the Mexican Official Standard NOM-187 issued by the Ministry of Health for the determination of the calcium oxide (CaO).

Procedure

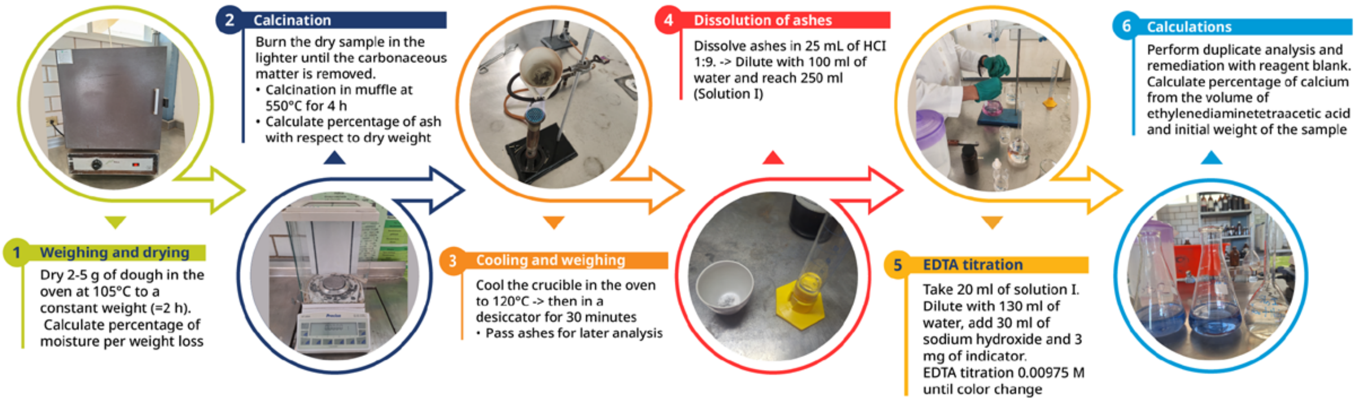

Figure 11. Experimental physicochemical testing process. Own elaboration.

Organoleptic Perception Survey:

A survey was conducted among 50 individuals randomly selected from a sample of approximately 1,200 regular tortilla consumers in Tonalá, Jalisco, México. The objective was to evaluate the organoleptic acceptance -flavor, texture, aroma, and appearance- of tortillas made with traditional dough versus those made with dough that included solids recovered from nejayote.

The results provided insight into the general public's opinion and helped determine whether the reuse of these solids affected the sensory quality of the final product.

Environmental label for tortillerías

Based on the survey's positive outcomes, the development of an environmental label was proposed for tortillerías that adopt the treatment device. This label would serve a dual purpose: on the one hand, to recognize environmentally responsible practices among producers—thus enhancing their reputation among consumers—and on the other, to promote a culture of responsible consumption by informing buyers that the tortillas were produced using less water, with proper waste management, and with increased nutritional value.

Results

- Water Consumption Reduction per Tortillería:

Table 2. Water savings with device implementation.

Device capacity (*Nejayote* capacity processed by batch)	Reduction of water consumption per month per *tortillería*	Reduction of water consumption per year per *tortillería*
30 liters	525 liters	6,300 liters
50 liters	875 liters	10,500 liters
80 liters	1,400 liters	16,800 liters

- Potential for National Water Savings through Implementation

By integrating the proposed treatment system across the country, a significant reduction in water usage per tortillería could be achieved, contributing to national water conservation efforts.

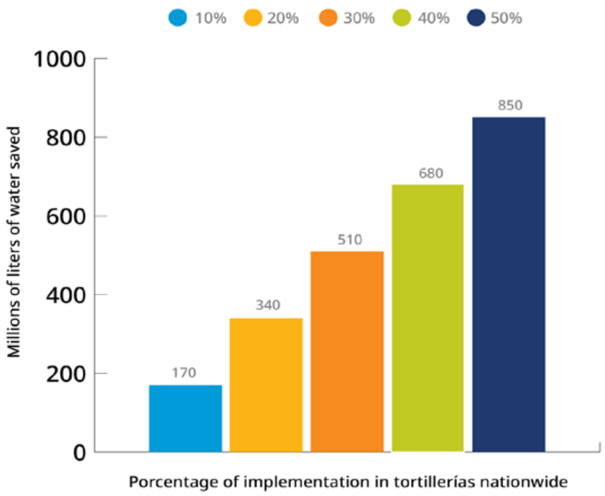

Figure 12. National water savings. Own elaboration.

- Reduction of Settleable Solids

Thanks to the prototype's design, an approximate 90% reduction in settleable solids in nejayote is expected, significantly improving the quality of the effluent. This efficiency was evaluated using a comparative analysis with the traditional Imhoff cone method, which recorded approximately 200 mL of settleable solids per liter of nejayote.

Figure 13. Sedimentation line in an Imhoff cone. Own photograph, 01/10/2025.

- Physicochemical Comparison: Traditional Dough vs. Enriched Dough

A series of tests were conducted to compare the physicochemical properties of tortillas made with conventional dough and those enriched with recovered nejayote solids, focusing on calcium content and other nutritional parameters.

Table 3. Results of physicochemical analysis of the dough. Own elaboration.

Analysis	Regular dough (without *nejayote*)	Enriched dough (with *nejayote)*
Moisture (%)	47.6%	45.2%
Ashes (%)	1.7%	1.7%
Calcium (%)	0.5%	0.6%

- Consumers perception on tortillas made with regular dough vs enriched dough with nejayote

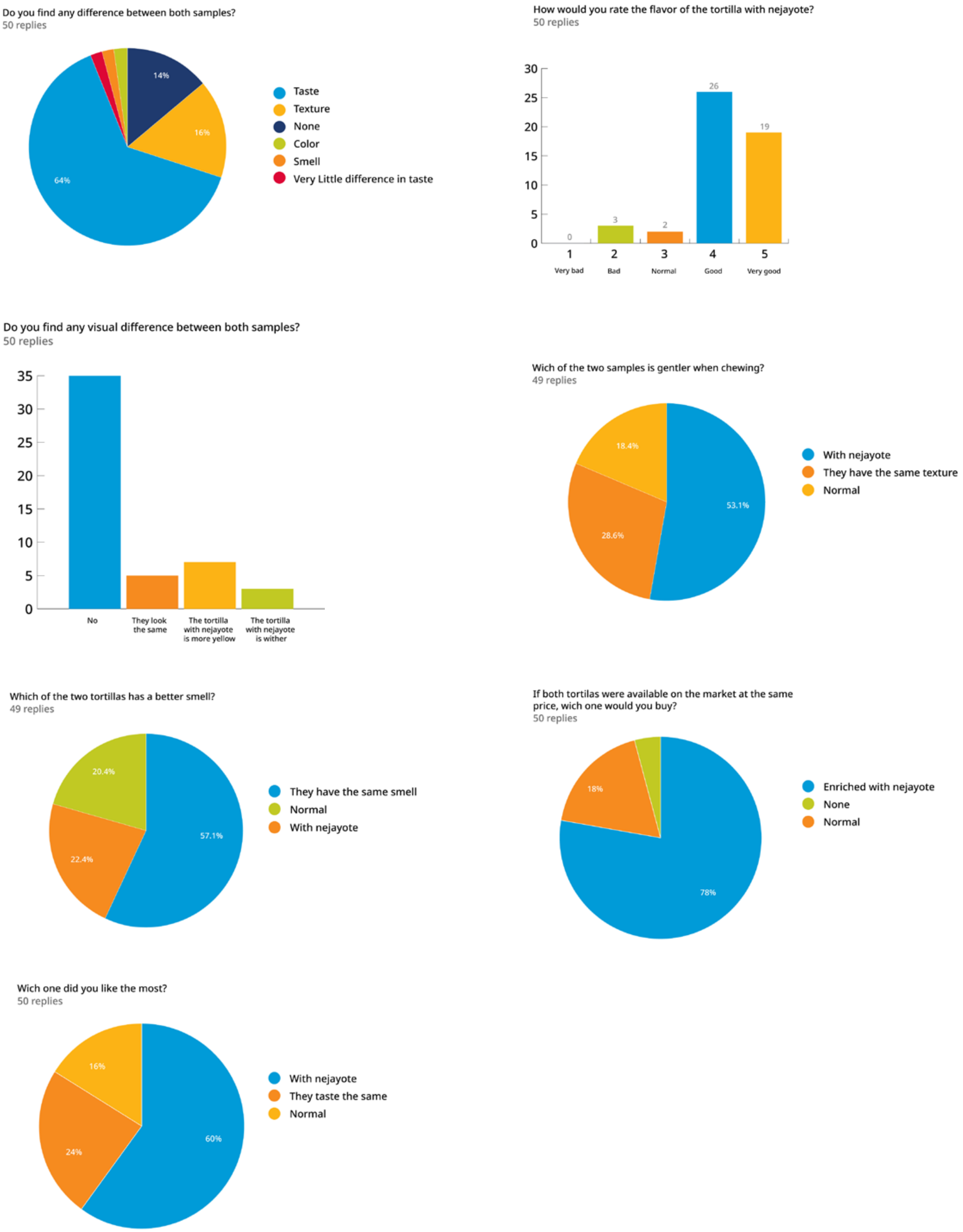

Figure 14. Survey results: Comparison of regular dough vs. enriched dough.

- Economic and Operational Feasibility of the Prototype

Reference Location: Tonalá, Jalisco, Mexico

Exchange Rate (approximate): 1 USD = 19.23 MXN (or 1 MXN = 0.052 USD)

Water Cost (SIAPA Guadalajara): $0.02043 MXN/Liter = $0.00106 USD/Liter

Average Market Value of Nixtamalized Dough (Estimated National Average): $12.00 MXN/kg = $0.624 USD/kg

Table 4. Financial analysis of the process. Own elaboration.

Key financial feature	30-liters device	50-liters device	80-liters device
Cost of the device. Initial investment	$322.41 USD	$416.02 USD	$572.02 USD
Water savings per month	$0.56 USD	$0.93 USD	$1.49 USD
Profit from increased production per month (Dough)	$44.74 USD	$74.60 USD	$119.34 USD
Total profit for tortilla producer per moth	$45.30 USD	$75.53 USD	$120.83 USD
Total profit for the tortilla producer per year	$543.60 USD	$906.36 USD	$1,449.96 USD
Annual return on investment	168.61%	217.87%	253.48%
Payback time	~7.1 months	~5.5 months	~4.7 months

Conclusions

1. The proposed device reduces water consumption and enables the recovery of usable solids from nejayote, which increases tortilla production and allows the investment to be recovered in under one year, making it a viable and cost-effective solution for producers.

2. The system enables water savings ranging from 525 to 1,400 liters, depending on the volume processed, representing a significant reduction in water use.

3. Implementing the device in 50% of tortillerías in Mexico could save up to 850 million liters of water annually.

4. The system is capable of removing up to 90% of solids present in nejayote, based on performance comparisons with the traditional Imhoff cone method.

5. Use of the device facilitates compliance with Mexican wastewater discharge standards by significantly reducing settleable solids in effluents.

6. Reintegrating the recovered solids into the dough enriches its calcium content without affecting the organoleptic properties of the tortilla, providing a valuable nutritional benefit.

7. A sensory evaluation survey with 50 participants showed good acceptance of tortillas made with enriched dough, with no significant differences in taste, texture, or color.

8. The system is compact and easily integrates into the daily operations of tortillerías without disrupting production. Additionally, the use of durable and low-cost materials supports replication in diverse contexts and suggests potential for scalability in other industries.

Contributions

The device for nejayote treatment and reuse provides a concrete solution to water scarcity and the lack of wastewater treatment in tortillerías, particularly in areas with limited infrastructure. Its implementation significantly reduces water consumption by enabling the reuse of clarified liquid, representing a key advancement in water sustainability.

This technology strengthens the four pillars of water security:

- Availability for people by protecting existing water resources,
- Support for productive activities by recovering water and usable solids, enhancing process efficiency,
- Environmental protection by reducing the discharge of pollutants into the environment, and
- Risk mitigation by preventing negative impacts on soils and water bodies.

Moreover, the system contributes to the achievement of several Sustainable Development Goals (SDGs) of the 2030 Agenda, particularly:

- **SDG 3** (Good Health and Well-being),
- **SDG 6** (Clean Water and Sanitation),
- **SDG 9** (Industry, Innovation, and Infrastructure),
- **SDG 11** (Sustainable Cities and Communities),

- **SDG 12** (Responsible Consumption and Production),
- **SDG 13** (Climate Action), and
- **SDG 14** (Life Below Water),

by promoting responsible, sustainable, and replicable practices in contexts where water management is both urgent and critical.

This project exemplifies how science and technology can be effectively integrated to address environmental, social, and economic challenges—from local initiatives to global strategies—aligned with the United Nations' vision for sustainable development. Its application generates benefits for the environment, public health, household economies, food production, and water stewardship, positioning it as a high-impact, scalable solution.

References

1. Atunes- Ricardo, M., Gutiérrez-Uribe J,.(2023, 5 enero). Nejayote, el residuo del maíz benéfico para la salud. TecScience. https://tecscience.tec.mx/es/uncategorized/nejayote-el-residuo-del-maiz-benefico-para-la-salud

2. Diaz- Mateos, J., Vega, D. De residuos agroindustriales a oportunidades de negocio. (s. f.). https://ciatej.mx/el-ciatej/comunicacion/Noticias/De-residuos-agroindustriales-a-oportunidades-de-negocio/252

3. Flores Saldaña, Ninel Amparo. (2014). "Reutilización de nejayote en la nixtamalización y su efecto en las propiedades microbiológicas, reológicas y texturales de masas y tortillas". (Tesis de Licenciatura). Universidad Nacional Autónoma de México, México. Recuperado de https://repositorio.unam.mx/contenidos/302586

4. Ochoa A., Vinegra-González G. (2008). Temas selectos de la cadena maíz-tortilla. México, D.F. Talleres de la Sección de Impresiones y Diseño de la UAM-I. pp. 144.

5. SAGARPA (2013). Servicio de Información Agroalimentaria y Pesquera. http://www.siap.gob.mx/cierre-de-la-produccion-agricola-por-cultivo/.

6. Secretaría de Medio Ambiente y Recursos Naturales. (2022). NOM-001-SEMARNAT-2021, Que establece los límites permisibles de contaminantes en las descargas de aguas residuales en cuerpos receptores propiedad de la nación. Diario Oficial de la Federación. https://www.dof.gob.mx/nota_detalle.php?codigo=5645374&fecha=11/03/2022#gsc.tab=0

7. Secretaría de Salud. (2020). Farmacopea de los Estados Unidos Mexicanos (13ª ed.). Comisión Permanente de la Farmacopea de los Estados Unidos Mexicanos.

8. Secretaría de Salud & Secretaría de Economía. (2003). NOM-187-SSA1/SCFI-2002, Productos y servicios. Masa, tortillas, tostadas y harinas preparadas para su elaboración. Especificaciones sanitarias. Información comercial. Métodos de prueba. Diario Oficial de la Federación. https://salud.gob.mx/unidades/cdi/nom/187ssa1scfi02.html

9. Soto-Cruz, Nueva York, et al. (2011). "El uso del nejayote como recurso: Avances y perspectivas". Revista Mexicana de Ingeniería Química.