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Developing a sustainable energy model for solar nixtamalization of native maize from Michoacán, Mexico

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A R T I C L E I N F O

Method name:
Sustainable nixtamalization model using solar energy

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A B S T R A C T

In Mexico, corn and the nixtamalization technique hold immense culinary and economic significance. Thus, optimizing and offering alternatives for this process is critical. This research proposes a solar-driven nixtamalization method customized for native maize varieties in Michoacán, Mexico. The objective is to present a technique that is energy-efficient, environmentally friendly, socially acceptable, and cost-effective. We devised a straightforward yet effective nixtamalization process utilizing the HSMC solar furnace. This method encompasses:

- Field research to understand the practices and traditions regarding nixtamalization and the most consumed maize varieties.
- Thermal determination and profiling of the solar oven to be used for each case study.

For the rural areas of Michoacán, solar nixtamalization presents a practical and eco-sustainable alternative in both energy usage and economic terms. However, those interested in its local application must consider that the duration may vary due to differing climatic conditions and maize types.

Specifications table

Subject area:	Environmental sciences and technologies
More specific subject area:	Environmental technologies
Name of your method:	Sustainable nixtamalization model using solar energy
Reference of original method:	N.A
Resource availability:	N.A

Description of protocol

Materials

- Solar devise (Fig. 1): a solar oven designed for the nixtamalization process is utilized. In crafting the design, climate conditions were taken into account, which is directly related with the concentration factor, the angle of sunlight acceptance as well as its

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Fig. 1. Solar device.

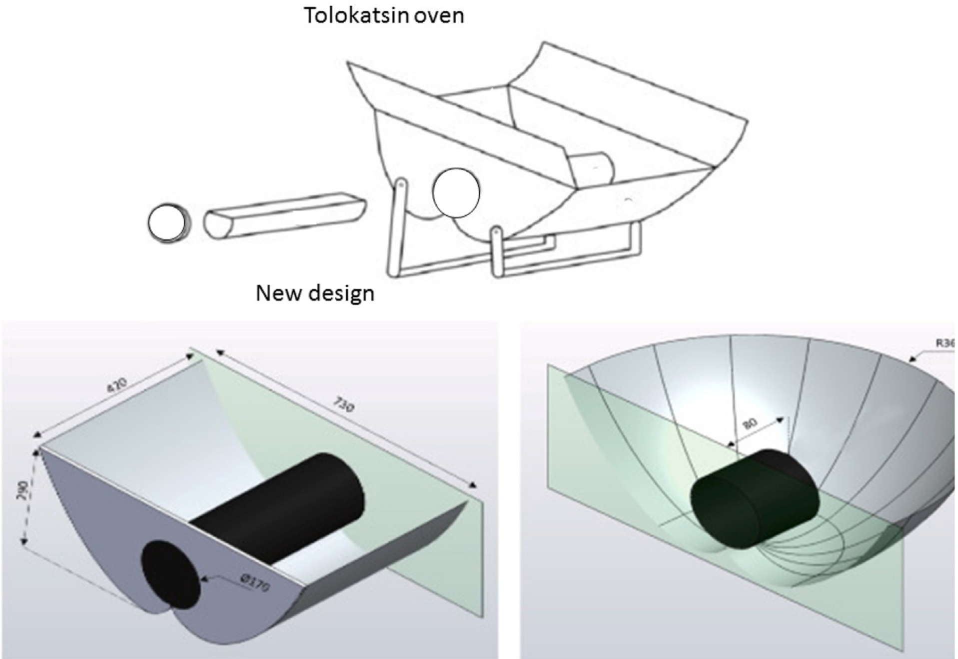

Fig. 2. Solar oven.

dimensions. The dimensions of the solar oven vary depending on the requirements of the household where it will be employed [1]. However, the nixtamalization oven was designed to remain in a fixed position throughout the corn cooking process, considering the climatic conditions of various communities in the state of Michoacán.

A portion of the new design is inspired by the tolokatsin oven design, while another part is influenced by the CPC stoves (Fig. 2) [2,3].

The development of these solar cooking ovens is also inspired by the creation of functional foods with physicochemical characteristics that offer nutrients and contribute to improving human health [4]. By considering environmental factors alongside traditional metrics such as energy efficiency and cooking performance, can develop a more holistic understanding of the environmental impact of cooking technologies. This approach promotes the adoption of technologies that are not only efficient and effective but also environmentally sustainable, paving the way for a more environmentally conscious future.

- Maize types: in Mexico, native corn has long been a cornerstone of traditional national cuisine, sustaining the livelihoods of numerous rural Mexican families. However, amidst the globalization trend, a "modern" dietary approach has emerged, gradually supplanting traditional dishes with processed alternatives, often unrelated to corn. This shift, compounded by factors like agricultural abandonment, the erosion of biocultural heritage, and climate change, poses a threat to the survival of native corn varieties. Thus, safeguarding the cornfields becomes an imperative task, demanding the formulation of short-term strategies. Michoacán is one of the states that has the greatest diversity of native corn and the third state with the highest corn production in the country [5]. Whereby four varieties of indigenous corn sourced from a community in Michoacan were subjected to the nixtamalization process (Fig. 3). These specific corn varieties were chosen due to their indigenous origin within the community and their accessibility for harvesting.

Fig. 3. Maize varieties.

Michoacán boasts a diverse range of maize varieties, encompassing 35 different types, some of which are notable for their unique nutritional profiles attributed to their distinct colors [6].

Methods

Tortillas, a staple food in Mexico and Central America, are made from nixtamalized corn, a process dating back to pre-Hispanic times involving cooking corn kernels in a calcium hydroxide solution. However, the quality and nutritional value of tortillas vary based on agricultural practices and food processing decisions [5]. Across various communities, such as those on the Purepecha plateau in central Mexico, food preparation commonly utilizes open-fire stoves, patsari (U-shaped stoves), and liquefied petroleum gas stoves, among others [7,8]. Solar ovens are in this study being used, replacing the traditional ones.

Nixtamalization is done in different ways depending on the place or there are simply differences in how it is made between families from the same place. That is why in the implementations of solar ovens, a demonstration is carried out with the measuring equipment, to show you the behavior of the oven.

- Field Investigation: the field analysis was conducted in the community of Tiríndaro, located in the municipality of Zacapu in Michoacán. Before implementing any solar devices, a participatory workshop is typically held with the community to discuss the form of intervention. In this instance, the nixtamalizing oven was no exception. During the workshop, a survey is conducted to understand the traditional nixtamalization methods practiced in the community because each community has its own process, and next to replicate the process as closely as possible by replacing the conventional cooking utensils and stove with a solar oven.
- From the participatory workshop, data were collected on the type of corn consumed in the community and the way it is prepared for different dishes, including tortillas. With the data collected from the community workshop, the solar oven or solar device is constructed. For example, based on the quantities of corn that are nixtamalized, the size of the cooking utensil is determined. During the workshop, information is obtained regarding the type of fuel nixtamalization process regularity they use, aiming to inform the community about the benefits of using solar devices. They are made aware of the amount of money they can save and that by not inhaling toxic gases such as smoke from wood stoves, respiratory diseases become less hazardous. The questionnaire was dispensed randomly across the community's four sectors, ensuring diverse and representative data collection.
- Data collection: to ensure effective implementation, it is crucial for users to witness scientific measurements being conducted. Therefore, workshops employ established standards and precise measuring instruments. Additionally, a variety of materials supplementary apparatuses for nixtamalization, and questionnaires for gathering relevant user insights and statistics, are utilized to ensure meticulous methodology implementation. The implementation of solar devices is guided by feedback gathered from questionnaires. As a result, each new implementation includes questions suggested by community members themselves. This approach allows community members to witness the incorporation of their suggestions into the projects.
- Thermal Profiling: validating the solar cooking system's efficacy is paramount. It guarantees ideal energy utilization and functionality. The prominent thermal metrics include: routine cooking power, thermal efficacy, cook span, and heating duration. These standard metrics furnish insights into these systems' effectiveness. The criteria proposed by the ASAE (American Society of Agricultural Engineers) elucidate thermal metrics, representation units, and quantification techniques [9]. The assessment of cooking power contemplates the meteorological conditions influencing a solar cooking system's operational efficacy. The oven was created to carry out the process of nixtamalization consistently, unaffected by cloudy weather or air currents, but it is not suitable for use during rainy conditions. The development of these solar cooking ovens is also inspired by the creation of functional foods with physicochemical characteristics that offer nutrients and contribute to improving human health [10]. By considering environmental factors alongside traditional metrics such as energy efficiency and cooking performance, can develop a more holistic understanding of the environmental impact of cooking technologies. This approach promotes the adoption of technologies that are not only efficient and effective but also environmentally sustainable, paving the way for a more environmentally conscious future.

  Experimental protocol: to conduct the evaluation of the solar oven, each variable, including the water temperature in the pot, ambient temperature, wind speed, and solar radiation, is recorded every 5 minutes until the water reaches approximately 90°C at the evaluation site. This process is repeated on-site until conditions are consistent.

Table 1
Percentages by type of corn.

Percentages	Type of corn consumed
46.3%	white corn
29.3%	yellow corn
14.6%	red corn
9.8%	blue corn

- Presentation to the Community: he first point is determining the nixtamalization times for the different types of corn. By rigorously setting and abiding adhering to these thermal standards and measurement techniques, our aim is to introduce a solar cooking solution tailored to the specific requirements of the Tiríndaro community needs. This approach emphasizes both energy efficiency and cooking effectiveness through a sustainability perspective.
- After experimenting with water the corn grains are nixtamalized: Nixtamalization is the cooking of corn grains, traditionally in water with wood ashes, alkaline compounds, calcium salts or weak acids. In this exhibition it was nixtamalized with calcium hydroxide. At its core, nixtamalization introduces calcium hydroxide to maize under raised pH and heat levels, amplifying its physical and dietary characteristics [10]. The niztamalization process begins when the corn grains, water and lime are introduced. The cooking process concludes when the husk of the grains loosens and emits a fragrance resembling that of cooked grains (tortilla dough). Seasoned tortilla makers recognize this distinctive cooking aroma. The cooking duration of the grains varies based on daily weather conditions and the quantity of corn being cooked.
- Solar Nixtamalization

The methodology for the solar nixtamalization adheres as closely as possible to the traditional community process. Trying to standardize the procedure with other communities, the method used to niztamalize is the following:

1. Place the cooking container in the solar oven with 2 liters of water. The oven should be exposed facing the sun and left for 35 minutes under clear-sky conditions or until reaching 80°C.
2. Add lime to hot water: Remove the lid of the heat receptor cylinder, take off 2/5 of the container's body, and add 40 gram of calcium hydroxide to the water. Stir for 15 seconds until fully dissolved. Reinsert the container, replace the lid, and let the mixture sit exposed to the sun for another 25 minutes.
3. Add the corn to the calcium hydroxide water: Remove the lid, take off 2/5 of the container, and add 2 liters of corn. Insert the container, replace the cover, and leave it for another 45 minutes.
4. Remove the oven from the sun or cover it with a blanket to prevent further radiation from heating the mixture and reaching the boiling point. The nixtamalization cooking process culminates by utilizing the thermal inertia of the pot and the water.
5. Finally, allow the mixture to rest overnight before washing.

It is recommended to start cooking one hour before solar noon, but people's needs vary, so cooking is often done while the sun is warming. Central to tortilla crafting, the resulting dough's qualities are deeply influenced by both the maize variety and cooking time. The consequences of cooking during cloudy hours or after solar noon can impact cooking times. However, as rural areas face increasing energy challenges and a pronounced reliance on wood, the search for ecological alternatives becomes crucial.

Against this backdrop, our research introduces a nixtamalization technique powered by solar energy, aiming for a holistic sustainable solution. Additionally, recent studies have been conducted on the nixtamalization of an endemic dark corn variety. These studies showed that when nixtamalizing dark corn using solar energy with a device specifically designed for this purpose, the antioxidants in the dark corn are retained in amounts approximately three to four times greater than when using the traditional nixtamalization method [6].

Results from the application of the method

The subsequent segment delineates the results achieved in line with the methodologies and strategies deployed, respecting the methodical and sequential order of the research.

Diagnostic outcomes

The evaluation conducted within the Tiríndaro community of Michoacán, Mexico was systematically executed, encompassing 40 random surveys dispersed among the 4 sections, with each section receiving 10 surveys. The conclusions are shown below: Table 1 shows the percentages by type of corn, Table 2 shows the quantities of corn used daily for nixtamalization.

Recognizing the consumed corn variety is vital since its hardness and thus cooking duration differs. An additional pivotal data point is the daily nixtamalized corn volume by families.

This information anchored the choice of the solar appliance for experiments, aspiring to furnish specific insights for prospective community adoption and tangible advantages.

Firewood remains the dominant energy medium for nixtamal preparation, rooted in tradition. This underscores the need for green technology integration. Employing a solar appliance for nixtamalization nullifies the dependency on other standard energy mediums, culminating in substantial savings.

Table 2
Quantities of corn used daily by families.

Percentages	Volume by families
34.1 %	2 L.
26.8 %	3 L.
29.3 %	4L
9.8 %	More than 5L

Table 3
Monthly fuel expense.

Percentages	spending
53.7 %	between $10 dollars and $20 dollars
46.3 %	between $20 dollars and $30 dollars

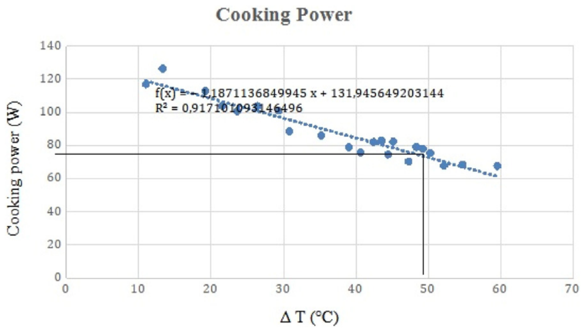

Fig. 4. Standard cooking power over time.

Inevitably, firewood usage contributes to environmental concerns like deforestation and augmented CO_2 emissions, amplifying climate change repercussions. Concerning monthly fuel expenses (Table 3):

Over 70 % of households undertake the process quintuple weekly. These statistics are paramount for the economic and energy assessment of the nixtamalization routine.

Below are Thermal Metrics of the Solar Nixtamalization Oven as dictated by the protocol.

Standard Cooking Power: the conventional cooking power is depicted via a graph, correlating the data procured during the experiments over time. The power, stabilizes at a 50 °C deviation. From this data, the main trend line (Fig. 4) is plotted, characterizing the solar stove with a power of 73 W.

Nixtamalization time analysis for maize varieties

The subsequent results outline the nixtamalization time frames for the four indigenous maize varieties hailing from the Ciénega de Tiríndaro, Michoacán, namely: white maize, yellow maize, red maize, and blue maize.

The delineated procedure within the methodology section was followed to determine the nixtamalization durations, unearthing noticeable variations across the four maize varieties. The adopted nixtamalization methodology aligned with [2]. This investigation unfolded within the Tiríndaro community in Michoacán. For each experimental attempt, the oven was fed with 3 L of potable water, 2 L of maize, and 150 g of calcium hydroxide (lime). Measurements were diligently recorded at 5-minute intervals, commencing from 10:00 solar time, following the regulations stipulated by ASAE S580. The process was initiated by elevating the temperature of 3 L water from ambient levels to 80 °C within the solar oven. Following this, 150 g of calcium hydroxide and 2 L of maize grains were introduced.

Once the stipulated cooking duration was realized, the grain's integrity was assessed by manually attempting to dislodge the pericarp from the grain. After this confirmation, the apparatus was either taken away from direct sunlight or shielded to halt further temperature escalation. Subsequently, the concoction was allowed to rest, spanning a duration between 8 and 12 h. Post-resting, the nixtamal underwent a mild rinsing procedure.

Table 4 offers a detailed overview of the evaluations conducted for each maize variant, indicating the time elapsed since the introduction of the grains into the heated alkaline solution up to the detachment of the pericarp. This observation was punctuated at 5-minute intervals to decipher the exact cooking duration mandatory for each maize category. To affirm the consistency and reliability of the results, every variant was tested at least six times.

Table 4
Nixtamalization Duration - White Maize. Nixtamalization Duration - Yellow Maize. Nixtamalization Duration - Red Maize. Nixtamalization Duration - Blue Maize.

Maize varietie	Temperature (°C)	Nixtamalization time (min)
White	80	40
Yellow	85	60
Red	80	45
Blue	85	50

Table 5
Quantitative Solar Energy Essential for Nixtamalization.

Maize varieties	Temperature (°C)	**Incident Solar Energy (J)**
White	80 °C	4,492,998
Yellow	85 °C	5,247,135
Red	80 °C	4,675,374
Blue	85 °C	5,119,380

In adherence to the ASAE S580 [2], the calorific requirement for nixtamalization was computed. This involved documenting parameters like solar timing, external atmospheric temperature, the temperature of the water, and the direct sunlight exposure specific to each maize type. The accumulated incident energy is cataloged in Table 2. Reiterating the emphasis on consistency and accuracy, each variant underwent six testing cycles (Table 5).

The integration of solar energy in the nixtamalization process presents a novel, sustainable approach to traditional maize preparation methods. From the data accumulated through this research, several key insights can be derived:

1. User-Centered Approach: The survey conducted in the Tiríndaro community, Michoacán, grounded this study in real-world contexts. It provided pivotal data about maize consumption habits, energy expenditure, and the community's willingness to adopt solar nixtamalization. The tangible relevance of these insights ensured the research's interventions were well-informed and tailored to the specific needs of the community.
2. Device Efficiency and Upgrades: Refinements made to the solar nixtamalizer, as detailed in the preceding sections, amplified its operational efficiency. These improvements not only augmented the device's thermal performance but also significantly streamlined the user interaction process, making it more user-friendly.
3. Cost-to-Benefit Analysis: The thermal parameters extracted from this study are particularly commendable when juxtaposed with the device's economic expenditure. Such a favorable cost-to-benefit ratio indicates the viability and sustainability of this device for widespread community use.
4. Diverse Maize Analysis: The in-depth investigation on the nixtamalization time frames for different maize variants, in conjunction with the requisite thermal energy, has elucidated crucial data. This knowledge aids in fine-tuning the device's operation, ensuring optimal efficiency regardless of maize type.
5. Potential for Broad Adoption: Given the device's efficiency and the community's inclination towards its usage, there is a substantial scope for implementing solar nixtamalization in the Tiríndaro region for a majority of the year. Such an extended period of applicability signifies its potential to revolutionize maize preparation in the community, offering both economic and environmental advantages.

In summation, the solar nixtamalization process epitomizes the confluence of tradition and innovation. It preserves the cultural significance of maize preparation in the Michoacán community while infusing it with modern sustainable practices. This endeavor not only offers a cleaner, greener method of maize preparation but also paves the way for further explorations into sustainable culinary practices in communities worldwide.

Ethics statements

Not applicable

CRediT author statement

José Ángel Rodríguez Morales: Conceptualization, Methodology, Software, Validity tests, Data curation, Writing - original draft. **Jessica Grizzel Maya Castro:** Conceptualization, Methodology, Software, Validity tests, Data curation, Writing- Original draft preparation. **Mauricio González-Avilés:** Supervision, Conceptualization, Methodology, Software, Validity tests, Data curation, Writing-Original draft preparation, Software, Validation. **Hermelinda Servín-Campuzano:** Validity tests, Validation, Writing- Reviewing and Editing

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Sustainable nixtamalization model using solar energy

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