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User-centered innovation approach: agave mead extractor

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Abstract. The maguey and pulque agroindustry in Mexico has remained underdeveloped, affecting quality and safety and limiting its competitiveness. This study outlines a sequential and iterative process for designing a device to extract aguamiel with added value for pulque producers in the northern State of Mexico over the period 2019–2024. The prototype was designed using a longitudinal, non-experimental research design framed within a qualitative frugal approach. The results indicate that the prototype reduces physical effort, enhances safety, and is positively received by producers. Areas for improvement related to efficiency and time satisfaction were also identified. The findings suggest that user-centred innovation contributes to stronger technological adoption and improvements in production processes. The participatory and iterative approach may serve as a replicable model for other small-scale agroindustrial technologies.
Keywords: Aguamiel, usability, technological innovation, rural development, pulque agave.

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1 Introduction

The primary sector in Mexico faces a dual challenge: on the one hand, the lack of economic growth; on the other, the lack of structural development. This situation leads us to reflect on the urgent need to promote rural development in a context characterized by technological stagnation, agriculture predominantly managed by older adults, and the importance of preserving traditional forms of production and food that are healthy and affordable.

In this scenario, the small-scale maguey and pulque agroindustry in central Mexico constitutes a significant source of economic income, generating permanent jobs in rural areas (Villavicencio, 2018; Blas-Yañez et al., 2019). This productive system, centered on the pulque agave, has been approached from various disciplines, highlighting its cultural, socioeconomic, ecological, nutraceutical, and even industrial value (Blas-Yañez & Thomé-Ortiz, 2021). However, the limited technological development in this rural agroindustry has not been systematically analyzed, which highlights multiple productive and commercial disadvantages, including the negative perception of the quality and safety of agave-derived products and their consequent marginal positioning in the market.

Faced with this reality, it is essential to reinvent processes in the pulque agroindustry to increase efficiency, improve product quality, and streamline the level of specialization required for the extraction of aguamiel. Within the framework of process innovation (OECD, 1997), this study focuses on describing the implications of designing innovative equipment for extracting this raw material, intending to reduce human physical effort and enhance both the safety and quality of aguamiel.

For this purpose, multidisciplinary alliances have been formed to develop the design of utensils and equipment for handling mead, ensuring hygiene and quality, utilizing technologies suitable for the context of small-scale rural producers. In this sense, technological change can be understood as the result of a reconfiguration of sociotechnical relationships and interactions that fosters innovation (Glover, 2019), where user-centered design plays a fundamental role. This approach enables the end user to be involved in all stages of the design process, utilizing specific methodologies and techniques, until a product is achieved that offers a positive experience (Bevan & Macleod, 1994; OECD & Eurostat, 2006).

This project aims to conduct user-centered evaluations to refine design solutions based on the results obtained. From the beginning, producers have actively participated in the innovation process, allowing their knowledge, practices, and needs to be incorporated. In this context, usability is recognized as a critical quality for the successful and efficient use of any product (Bevan & Macleod, 1994).

Active cooperation between production units and the university has been crucial in promoting innovation activities that contribute to the revitalization and preservation of the rural pulque agroindustry. This process has been iterative: various traditional tools and prototypes for aguamiel extraction were designed, tested, reviewed, and refined based on user feedback to achieve a functional, acceptable, and relevant outcome for the task. Therefore, the objective of this work is to describe the iterative design process of a device for extracting aguamiel, with use value for pulque producers in the northern part of the State of Mexico, developed between 2019 and 2024.

This manuscript is organized as follows. Section 2 describes the materials and methods used for an interactive qualitative design of a user-centered aguamiel extraction device. Section 3 shows the results obtained from an iterative mead extraction design and the used-center validation obtained. Section 4 states some discussions, and Section 5 presents the conclusions of the paper.

2 Materials and methods

This report employs a longitudinal research design with a qualitative approach (Fig. 1), which describes the iterative design process of a user-centered aguamiel extraction device. The reporting period runs from September 2019, when the innovation idea was conceived, to 2024, when a series of improvements have been developed based on end-user testing and their recommendations, with the help of a multidisciplinary research group and close ties between academia and the rural pulque agroindustry in northern Mexico State.

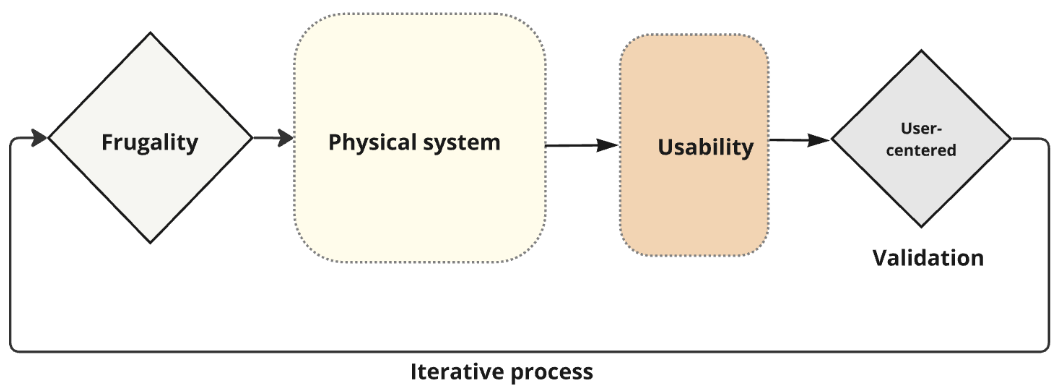

Fig. 1. Stages of the design process of extraction devices

Data collection was conducted through techniques such as direct observation using an observation guide and interviews supported by an interview form. A field diary, a photographic archive of the intervention and design processes, and other primary sources of information, such as undergraduate theses completed between 2019 and 2024, documenting the innovative design efforts for this agroindustry.

The device itself is considered the object of study, in an iterative context between the end user and technological innovation, through the connection of students and researchers from the Polytechnic University of Atlacomulco with producers of pulque maguey and derivatives from Jiquipilco, A.L.P.R. In this context, this research report describes the creative and design process that underpins the electromechanical device for extracting aguamiel, before its evaluation in a real-life context.

Given the inherent complexity of creating new technologies to strengthen small-scale production systems, this study contributes by describing the different phases of creation and design, with an emphasis on the creative process of developing ideas to generate improvements to the raw material collection process, the actors and communication channels used to gather input for improvements in favor of creating a user-approved version for the task, and how successes and problems inherent to the innovation are managed.

The case description encompasses variables of user-centered design (UCD), a proposal grounded in the design of technological innovation. It focuses on problems of functionality, usability, interaction, or needs that the prototype has failed to meet over the past 5 years. Based on the methodology of Bevan & Macleod (1994), the extent to which the innovation proposals met the characteristics and attributes necessary for a product to be usable was assessed.

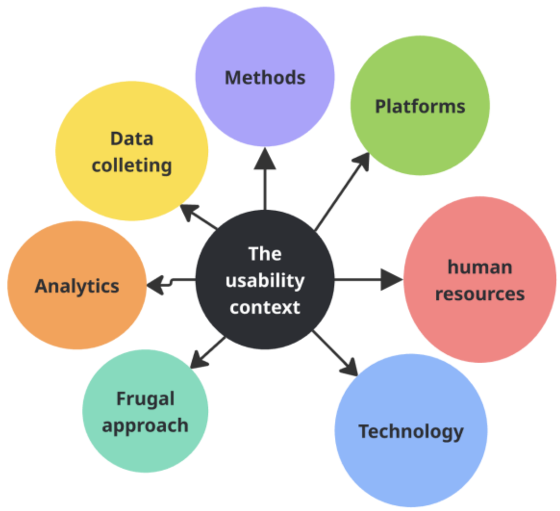

Fig. 2. Phases of the usability context

The first research phase involved documenting the usability context (Fig. 2), aiming to systematically and practically identify the usage specifications for developing the design (Bevan & Macleod, 1994). This phase describes all the components of the overall system that impact the quality of use, including users, tasks, equipment, and the physical environment. End users were considered those producers dedicated to the daily extraction of mead and willing to collaborate in a methodical analysis.

The use of technological innovation and the analysis of observations were documented, which involved several informatics and computational elements implicit or necessary for the development and evaluation of the device, as follows: Qualitative Data Recording and Processing, Usability Assessments, the design process of the devices, digitalization of drawings, schematics, and technical reports.

After prototyping innovative options for the task, the attributes through which the product contributes to effectiveness, efficiency, and satisfaction in achieving specific objectives within specific environments were analyzed using the usability method (Bevan & Macleod, 1994). In this phase, all designed prototypes were recursively evaluated to identify operational issues with the prototype; these are essential for the device's appropriation, improving the competitiveness of the production system under study, and channeling its proper utility or value to the end user.

Each design and prototype is validated based on:

a) **Effectiveness:** the extent to which the intended usability objectives of the overall system are achieved, that is, the accuracy and completeness with which these goals can be achieved (task outcome)
b) **Efficiency:** which includes the resources such as time, money, or mental effort expended in achieving the intended objectives (human efficiency, time efficiency, or economic efficiency).
c) **Satisfaction:** which indicates the extent to which the user finds the overall system acceptable; these indicators were measured through attitude rating scales to document and interpret positive and negative feedback during use. Satisfaction measurements are relevant because they provide a valuable indication of users' perceptions of usability, even if measures of effectiveness and efficiency cannot be obtained (Bevan & Macleod, 1994).

The documented material provided compelling evidence for the prototype designers and developers regarding the device's usability and specific issues, which were refined over time and with the intervention of various specialists in the areas of mechatronics engineering, manufacturing, and agri-food production.

To answer the research question: What is the level of effectiveness, efficiency, and end-user satisfaction of the proposed innovations for the mead extractor?, the research results were grouped into the following sections: i) Usability contextualization; ii) Prototype-level usability evaluation; iii) Integrated improvement recommendations. The information was analyzed in double-entry tables, which indicated the different designs and the corresponding evaluations for each. The improvements implemented to obtain a final prototype, before its evaluation in a real-world environment and subsequent patenting, are also described.

3 Results

This section describes the primary users of the innovation, as well as the activities, strategies, and issues that arose during the iterative development process, aimed at enhancing the prototype's design. These actions enabled the documentation of its effectiveness, efficiency, and level of satisfaction before its evaluation in a real-world context. The information obtained is essential for the innovation's functioning and appropriation, with the intention of improving the competitiveness of the production system under study.

3.1 Usability context

During this phase, field visits and support were provided to maguey pulquero producers (potential users of the prototype) during their aguamiel extraction sessions. The objective was to observe and document the device's usability context through video recordings, photographs, audio, georeferencing, and written records in field diaries. The video clips obtained provided valuable evidence for the prototype's designers and developers, allowing them to identify performance issues and unmet needs. This documentation helped enrich the design process from a user-centered perspective.

3.1.1 Description of the extraction equipment

The aguamiel harvesting process has a long tradition among the indigenous peoples of central Mexico (Ortiz-Basurto et al., 2008). This activity remains relatively low-tech, with no significant changes since pre-Hispanic times (Trejo, 2017).
In 1928, regulations for the production, introduction, transportation, and sale of pulque in the then Federal District were published. These regulations established parameters for hygienic aguamiel harvesting, including the use of easily washable and sterilizable utensils and pumps. In this context, the use of the acocote and the oral suction system, both still in use today, were prohibited (Valadez, 2014). Aguamiel harvesting occurs under diverse technological and sociocultural conditions. In the study area, four main types of utensils were identified for collecting aguamiel, extracted twice a day throughout the year:

- Cup: Can be made of metal, plastic, or clay.
- Natural acocote: Made from the dried fruit of the Lagenaria siceraria plant, perforated at both ends and hollowed out to form a cylinder.
- Fiberglass acocote: Retains the shape of the natural acocote, but with greater strength and durability.
- Homemade acocote: Made from a two-liter PET bottle, fitted with a hose, with a perforated base to simulate the functionality of the natural acocote, offering advantages in cost, ease of cleaning, and durability.

3.1.2 User Description

Those responsible for extracting aguamiel, traditionally known as tlachiqueros, are mostly men over 60 years of age with limited education. These workers acquire their knowledge empirically and through oral transmission from childhood within the family nucleus (Pecci et al., 2017). This know-how constitutes an incorporated cultural capital that is currently at risk due to the lack of generational renewal and the predominance of this knowledge among older adults (Blas et al., 2020).

3.1.3 Description of the task

The extraction of aguamiel depends on the empirical knowledge accumulated by the tlachiqueros. This ancient process consists of collecting the liquid (sap) that accumulates at the bottom of the stem cavity of the pulquero agave (Agave macroculmis, A.

mapisaga, A. mapisaga var. lisa, A. salmiana, A. angustifolia, A. ferox, A. salmiana subsp. crassispina, and A. tecta) (Colunga-García et al., 2007).

The oral suction performed by the operator allows the aguamiel to enter the interior of the acocote. According to the producers' testimonies, the narrow end of the acocote is fitted with a cow horn cap, whose convex shape allows it to reach the bottom of the bowl and extract a greater amount of liquid, unlike straight polyethylene tubes (Carriola and González, 2019:26). Once the acocote is full, the tlachiquero covers the bottom hole with his finger, acting as a valve to prevent the aguamiel from spilling. The contents are then transferred to larger containers for transport. This procedure is repeated twice a day for each plant, yielding between 0.4 and 5 liters per harvest. A tlachiquero can tend between 20 and 100 magueys daily.

3.1.4 Description of the environment

The maguey pulquero plantations in Jiquipilco, State of Mexico, are located on difficult-to-access mountain slopes, with steep inclines and no roads suitable for freight vehicles (López and Blas, 2024). Operators must travel on foot or with the help of pack animals to transport the aguamiel.

The sap is extracted from the cajete, a cavity at the base of the agave flower, which can reach dimensions of up to 30 cm wide, 80 cm deep, and with an internal diameter of 46 cm. Harvesting takes place daily in two shifts: between 4:00 and 8:00 a.m., and between 4:00 and 7:00 p.m. The quantity of aguamiel varies depending on the resting time, the weather, the phase of the moon, and the physiological state of the maguey. In the first few weeks, an average of 400 ml is harvested per session, while at peak production, between 1.5 and 5 liters can be obtained per plant. Towards the end of the production cycle (around 90 days), production decreases again to 400 ml per session (Carriola and González, 2019:29).

It should be noted that this work is carried out under any weather conditions (rain, cold, hail), as skipping the harvest could lead to internal fermentation or significantly reduce aguamiel production due to poor management of the maguey during production.

3.2 Usability validation

3.2.1 Comparison of the usability between traditional utensils for collecting mead

The tools traditionally used by mead producers were evaluated based on three key criteria: effectiveness, efficiency, and user satisfaction. This evaluation was conducted in a real-life context, based on direct observations by both users and the technologists involved in the innovation project (see Table 1).

The observations recorded resulted from the exchange of information between suppliers (designers) and users, in an initial approach aimed at identifying areas of opportunity within the production process. This process was crucial in initiating the design of innovative solutions that effectively addressed the identified problems (OECD & Eurostat, 2006, p. 93).

This research stage was crucial for obtaining accurate measurements of user performance in using traditional tools, based on indicators of effectiveness, efficiency, and satisfaction. The coordination of field survey and analysis activities fostered an iterative feedback process between designers and users, which is essential for developing relevant and functional innovations. This approach is essential for the proper management and dissemination of innovation (OECD & Eurostat, 2006, p. 93).

Table 1. Usability analysis of traditional agave mead collection utensils

Utensil	Effectiveness	Efficiency	Satisfaction
Cup 	**Low.** It fails to collect the honeydew at the bottom due to its flat shape, which is incompatible with the plant's concave cavity.	**Medium.** Requires repeating task several times due to limited capacity. **High cost:** reusable or recyclable. **Medium in effort:** requires multiple maneuvers.	**Low**. Preference is given to elongated instruments that allow for complete extraction. **Low safety:** possible contact of hands or nails with the liquid.
Traditional Acocote (Lagenaria siceraria) 	**High.** Its elongated shape allows the liquid to be collected in one go.	**High.** Fast harvesting (~10 seconds). **Low cost:** fragile, requires frequent replacement, and is difficult to obtain. **Medium physical effort:** requires technique, training, and lung strength.	**Low.** Risk of contact with breath and hands; fragile with constant use.
Glass-fibre acocote 	**High.** Improved shape and strength compared to natural.	H**igh.** 10-second response maneuver. **Medium:** cost and availability. **Medium in physical effort:** requires technique and lung strength.	**Low.** Contact with breath and hands; risk of contamination.
Acocote made from recycled material (PET and PVC) 	**High.** Good shape, weight, and strength.	**High.** 10-second response maneuver. **Highly cost-effective:** recycled materials, easy to manufacture. **Medium effort:** requires training and lung strength.	**Low.** Same risk of contamination from contact with breath and hands.

3.2.1 Comparison of prototypes for the mead extraction

They began in 2019 with students from the Manufacturing Technology Engineering program, who designed a mechanical suction device based on Pascal's theory and re-engineered the extraction mechanisms of the water gun (Carriola and González, 2019). Other efforts were made with students of Robotics Engineering, who employed a sequential method and a mechatronic approach for designing functional extraction devices for the task between 2020 and 2024 (Table 2).

Table 2. Projects for the design and maintenance of extraction devices for mead 2019-2024

Date	Project	Author	Adscription	Type
2019	Hygiene improvement and control project for the aguamiel production process in family production units in Jiquipilco, State of Mexico	Francisco Javier Carriola Alva y José María González González	Engineering in Manufacturing Technologies	Estancia II
2020	Design and development of a proposal for the extraction of aguamiel from pulquero agave	Luis Andrés Licona Molina	Robotics Engineering	Estadía
2020	Design and construction of a device for extracting honey water with a focus on 4.0.	Luis Antonio Trejo Cerecero	Robotics Engineering	Estadía
2021	Validation and instrumentation of a mead extraction device by pumping	Kevin Uriel Hernández González	Robotics Engineering	Estadía
2024	Design of an electromechanical device for extracting honey water: a multidisciplinary approach to addressing agricultural production needs	Jorge Eduardo Campos Mejía	UPIITA-IPN	"Delfin" Science Summer Stay

The devices developed at the Polytechnic University of Atlacomulco were evaluated based on their effectiveness, efficiency, and end-user satisfaction. Pulque producers conducted the evaluation both in a virtual room and in the field. They were informed of the adjustments made, as their observations were instrumental in improving the design and readjusting the functions. Among the most relevant aspects were ease of use, performance in task execution time, and construction materials.

Table 3 presents the results of the producers' observations and opinions on the designed devices, obtained through a face-to-face process in which each participant experienced the use of the device. These subjective measurements were obtained during the field evaluation of the devices, which enabled us to assess the difficulty users encountered when performing the extraction task with the created devices. As other authors point out, to foster innovation in a company, it is crucial that users are aware of what works for their processes (Scafuto et al., 2018).

Table 3. Usability analysis of devices designed for collecting mead

Utensil	Effectiveness	Efficiency	Satisfaction
Natural acocote reinforced with fiber and resin, with two attached nozzles, printed with PLA in 3D 	**High:** maintains an elongated shape and adequate size to collect the liquid in a single effort (introduction and suction).	**High** time commitment: 10 seconds of maneuver response time. **Low-cost commitment:** high cost of fiber, resin, and specialized sales. **Low human effort commitment:** requires high specialization and physical fitness.	**Low:** with respect to safety, since there is direct contact with the breath and hands with the liquid during filling.
Mechanical suction device	**Medium:** maintains an elongated shape and adequate size to collect	**High:** respect for time: 10 seconds of maneuver-response.	**Low:** The materials are not food-grade, have a short shelf life, and the adhesive

	liquid, but requires greater physical effort to achieve suction.	**High respect for cost:** easily accessible materials cost $110. **Low respect for human effort:** requires a lot of strength to maneuver.	tape used represents a source of contamination, in addition to requiring significantly more physical strength for the suction and retraction tasks.
Electromechanical device 1.0 	**High:** Good shape, weight, and strength, with wheels and fasteners that make it easy to maneuver.	**Low time commitment:** more than 20 seconds of maneuver-response time. **Low cost:** construction costs more than 8,000 Mexican pesos. **High human effort:** requires no specialized training, just the push of a button.	**Low:** Satisfaction regarding task time is low because it is not compatible with the traditional 10-second task process.

3.2.1 User feedback recommendations for improvement

Following the usability analysis, the results indicate that one of the main improvements requested by users was the speed of task completion, as well as the use of materials that ensure the safety of the extracted raw material in liquid form. In response, the students' work sought alternatives to develop a pumping system that would meet user expectations while remaining lightweight to maintain a favorable ergonomic balance. Additionally, alternative energy sources were explored to facilitate their use and reduce associated costs. Thus, satisfaction issues were identified, leading to improvements in the prototype for the client.

In this regard, work was conducted on incorporating a peristaltic pumping mechanism and utilizing a food-grade hose to prevent contact contamination. The roller system enables internal air to facilitate the extraction function, eliminating the need for system purging upon activation, and also corrects the flow rate, a feature that previous versions of the device lacked. This helps meet the needs of the extraction context (Plata, 2022), also providing protection against hygiene and respiratory risks.

The electronic design incorporated into the devices aims to help farmers have a more efficient harvesting alternative. It also enables data collection on the levels of collected sap, pH, and Brix degrees, facilitating informed decision-making to improve the quality of the final product (Trejo, 2020).

4 Discussions

While technological advancement is often seen as the primary driver of innovation, this study highlights the cultural dimension as equally critical. In the case of the pulque agroindustry, innovation must respect traditional knowledge systems, values, and practices to be effectively adopted. This should emphasize the need for solutions that are socially and culturally embedded. They can be discussed because they have a qualitative approach focused on the user.

i) User-Centered Design Strategy for the design of new utensils and devices: This iterative, user-centered approach requires best practices in design thinking that constantly evolve, as involving users early and often ensures robust devices where the final prototype meets current needs. This may reduce design failure rates.

ii) Demystifying Pulque Production: A notable secondary impact of the innovation is its potential to demystify and modernize perceptions of pulque production, which has traditionally been an informal practice. The introduction of user-centered tools may help elevate pulque within markets, enhancing its legitimacy and economic potential.
iii) Inclusion and Rural Development: The design's simplicity and usability enable non-expert users to participate in the extraction process, thereby supporting youth migration by offering viable employment alternatives in local contexts. Moreover, it may reinforce the idea that innovation should also be socially and economically efficient.
iv) Scalability and Regional Impact of Agroindustrial Automation. Incorporating robotics and automation opens the door for scalable and technological innovations. Such interventions may redefine rural manufacturing, making it more competitive while improving safety, consistency, and profitability.
v) Structural Challenges and the Role of Institutional Collaboration: Rural innovation typically lacks access to risk capital. This study highlights the importance of collaboration among academia, government, and local producers, particularly in the context of agriculture 4.0.

5 Conclusions

It is concluded that to introduce innovations that improve existing processes, it is essential to consider the cultural aspects of the pulque agroindustry, ensuring the device is adopted and valued by users. Therefore, it is crucial to maintain a user-centered design approach, under an iterative process that has strengthened innovation and the development of the 2024 prototype.
As other authors point out, innovation is often associated with changes in processes or products. What a company must do is identify the right combination of innovations that fit its objectives. Likewise, it is essential for entrepreneurs to understand what innovation entails and how they can leverage it in their companies (Scafuto et al., 2018).

This work seeks to contribute to the development of innovative tools that optimize production processes in the pulque agave value chain. Furthermore, the use of the device, along with adapting the design to meet user needs, has the potential to demystify pulque production in the medium term. Furthermore, the device's ease of use will enable the inclusion of inexperienced individuals in the aguamiel extraction process, promoting job placement and potentially reducing the rural exodus in search of alternative employment.

The integration of advanced technologies in the design of these devices, such as robotics and automation systems in agroindustry, can facilitate the inclusion of more efficient and accessible manufacturing processes. As technological capabilities in the region improve, access to affordable innovation can transform the local agroindustry, improving working conditions and the sector's sustainability.

The main limitations identified are the high investment cost and the challenges in managing financing for innovations. However, collaboration between academia, government, and the local community is essential to ensure the success of this initiative.

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