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Presentation of Content

In the first article we present, *Retrospective analysis of maize breeding for the humid tropic in México* by Sierra-Macias, Mauro, Ríos-Isidro, Clara, Gómez-Montiel, Noel Orlando and Barrón-Freyre, Sabel, with adscription in Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias as the next article we present, *Solar energy and agriculture: Revolutionizing water pumping in the field* by Campos-Donato, Eugenio Josué, Jiménez-Márquez, Omar, Oropeza-Tosca, Diana Rubí and Gómez-Álvarez José del Carmen, with adscription in Villahermosa Institute of Technology and Tecnológico Nacional de México, as the next article we present, *Administrative Management and Profitability of Pineapple Cultivation at the UMI-ITUG* by Balderrabano-Briones, Jazmín, Utrera-Velez, Youssef , Rodriguez-Agustin, Griselda and Soria-Vazquez, Reyna Susana, with adscription in TecNM / Instituto Tecnológico de Úrsulo Galván, as the next article we present, *Use of QR codes in school laboratories* by Mex-Álvarez, Rafael Manuel de Jesús, Yánez-Nava, David, Guillen-Morales, María Magali and Chan-Martínez, Roger Enrique, with adscription in Universidad Autónoma de Campeche, as the next article we present, *Preparation and shelf life evaluation of a fermented hot sauce based of costeño chili peppers Capsicum annuum L. from Tabasco, Mexico* by González-De La Cruz, Sesilu Montserrat, Velázquez-Martínez, José Rodolfo, González-De La Cruz, José Ulises and De La Cruz-Leyva, María Concepción, with adscription in Universidad Juárez Autónoma de Tabasco, as the next article we present, *Current techniques for evaluating peach quality: Analysis and synthesis of the state of the art* by Huerta-Flores, Humberto, González-Meneses, Yesenia Noemí, Pedroza-Méndez, Blanca Estela and Ramírez-Cruz, José Federico, with adscription in Tecnológico Nacional de México, as the last article we present, *Cajititlán Lagoon: Conservation and utilization of endemic fish biodiversity, a sustainable source of energy* by Vizcaíno-Rodríguez, Luz Adriana, Garcia-Vizcaíno, J.A., Caro-Becerra, Juan Luis and Michell-Parra, J. Guadalupe, with adscription in Universidad Politécnica de la Zona Metropolitana de Guadalajara and Universidad de Guadalajara.

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Article

Retrospective analysis of maize breeding for the humid tropic in México

Análisis retrospectivo del mejoramiento genético de maíz para el trópico húmedo de México

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Abstract

During more than seven decades of research in genetic improvement of maize for the Mexican tropics at Campo Cotaxtla [INIFAP], 16 hybrids have been released: 10 open-pollinated varieties and 3 synthetic ones. The methods used have been population improvement based on recurrent selection, which generates open-pollinated varieties; The integration of broad genetic compounds that function as genetic reservoirs for the derivation of inbred lines and for population improvement; hybridization that exploits the heterotic effect by crossing individuals with relative genetic divergence and good specific combining ability. Synthetic varieties, with genetic recombination of inbred lines with good performance per se and good general combining ability. The H-520 and H-518 hybrids, and the VS-536, V-537C, and V-540 varieties, are currently in use with good yield, adaptation to humid tropical regions, and ease and profitability of seed production.

Objectives

a) To develop varieties, hybrids and synthetics with high potential yield and wide adaptability to the humid tropic
b) To develop grain and seed production technology and c) to show to farmers and technicians the results gotten in maize research.

Methodology

The methods used have been population improvement based on recurrent selection, which generates open-pollinated maize varieties; The integration of broad genetic compounds that function as genetic reservoirs for derivation of inbred lines and for population improvement; hybridization that exploits the heterotic effect by crossing individuals with relative genetic divergence and good specific combining ability. Synthetic varieties, with the genetic recombination of inbred lines with good performance per se and good general combining ability.

Contribution

During more than seven decades of research in maize genetic improvement for the Mexican tropics at Campo Cotaxtla, INIFAP, 16 hybrids have been released: 10 open-pollinated varieties and 3 synthetic ones. The H-520 and H-518 hybrids, and the VS-536, V-537C, and V-540 varieties, are currently in use with good yield, adaptation to humid tropical regions, and ease and profitability of seed production.

Hybridization, population improvement, synthetics

Resumen

Durante más de siete décadas de investigación en mejoramiento genético de maíz para el trópico mexicano en el Campo Cotaxtla, INIFAP, se han liberado 16 híbridos, 10 variedades de polinización libre y 3 sintéticos. Los métodos utilizados han sido el mejoramiento poblacional a base de selección recurrente, con la cual generan variedades de polinización libre; La integración de compuestos de amplia base genética que funcionan como almacenes genéticos para la derivación de líneas endogámicas y en el mejoramiento poblacional; La hibridación que aprovecha el efecto heterótico al cruzar individuos con relativa divergencia genética y buena aptitud combinatoria específica. Las variedades sintéticas, con la recombinación genética de líneas endogámicas con buen comportamiento *per se* y buena aptitud combinatoria general. Los híbridos H-520 y H-518, las variedades VS-536, V-537C y V-540, en uso actual con buen rendimiento, adaptación a la región tropical húmeda, facilidad y rentabilidad en la producción de semilla.

Objetivos

a) Desarrollar variedades, híbridos y sintéticos de maíz de elevado potencial de rendimiento y adaptación al trópico mexicano
b) Desarrollar tecnología de producción para granos y semillas; c) Dar a conocer a los agricultores y agentes de cambio los resultados obtenidos de la investigación en maíz.

Metodología

Los métodos utilizados han sido el mejoramiento poblacional a base de selección recurrente, con la cual generan variedades de polinización libre; La integración de compuestos de amplia base genética que funcionan como almacenes genéticos para la derivación de líneas endogámicas y en el mejoramiento poblacional; La hibridación aprovecha el efecto heterótico al cruzar individuos con relativa divergencia genética y buena aptitud combinatoria específica. Las variedades sintéticas, con la recombinación genética de líneas endogámicas con buen comportamiento *per se* y buena aptitud combinatoria general.

Contribución

Durante más de siete décadas de investigación en mejoramiento genético de maíz para el trópico mexicano en el Campo Cotaxtla, INIFAP, se han liberado 16 híbridos, 10 variedades de polinización libre y 3 sintéticos. Los híbridos H-520 y H-518, las variedades VS-536, V-537C y V-540, en uso actual con buen rendimiento, adaptación a la región tropical húmeda, facilidad y rentabilidad en la producción de semilla.

Hibridación, mejoramiento poblacional, sintéticos

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

In México Maize is the most important crop because it is part of the diet for human consumption, the sown area, and generates 36% of the agriculture production value. During 2022, there were sown in México, 7.47 million of hectares with maize, which of them, 6.904, were for grain production, with 3.90 t ha^{-1} in average yield and production of 26.55 million tons, with an apparent *per cápita* consume of 338.10 kg; Besides, 17.40 million tons of yellow grain were imported for industry and animal feed [SIAP, 2022].

Maize in Mexico have multiple uses as grain, fodder and industrial use; however, the most important use is the direct consumption through the tortillas, tamales, Huchepos, Corundas, Atoles, Totopos, Tlayudas, Pozole, among others. Through the nixtamalization process, there have been created multiple dishes and ways for direct consumption. Tuxpeño is the most distributed and used race in the humid tropics and has been the basis for genetic improvement [Sierra *et al.,* 2024].

Corn breeding generates byproducts such as open-pollinated varieties, synthetics and hybrids. The genetic resources that have served as the basis for genetic improvement have included native corn collections, the integration of corn germplasm composites with a broad genetic base [CABGs] that function as genetic repositories for getting inbred lines or in recurrent selection.

Population improvement in corn crop takes advantage of the additive portion of genetic variance present in populations and generates byproducts that are high yielding, widely adapted, open pollinated varieties. In hybrids, genetic variance, additivity deviation, and heterosis expressed in maize are exploited when crossing parents with relative genetic divergence [Reyes, 1985]. Synthetic varieties take advantage of the good performance *per se* of inbred lines and their general combining ability to obtain high yield and widely adapted varieties. They offer the advantage of greater adaptability. In addition, farmers can use them for several planting seasons without affecting grain yield. Seed production is also profitable and easier, Reyes [1985].

General Combining Ability [GCA] describes the average performance of a parent in their crosses, while Specific Combining ability [SCA] refers to combinations that are significantly superior to those expected. In the absence of epistasis, GCA reflects additive effects, while SCA reflects dominance effects [Márquez *et al.,* 1983; Reyes, 1985].

High quality protein maize is derived from the use of the opaque mutant gene o2o2, expressed in its homozygous recessive version with higher content of Lysine and Tryptophan, essential aminoacids in food [Mertz *et al.,* 1994]. Larkins *et al.* [1994] indicaron que, los maíces con el gene o2o2 contienen de 40 a 50% más Lisina y de 35 a 40% más Triptofano [Andrés *et al.,* 2016].

Genetic improvement of maize in the humid tropic of Mexico began in 1943 by the predecessor organizations of the current INIFAP, such as the National Institute of Agricultural Research [INIA], formed by the fusion of the Institute of Agricultural Research [IIA] and the Office of Special Studies [OEE] [Reyes, 1971]. Over seven decades of continuous research, 16 hybrids, 10 open-pollinated and 3 synthetic varieties have been released, with great acceptance by farmers. Among them, the following are currently in use: H-520, H-518, VS-536, V-537C, and V-540 [Sierra *et al.,* 2008; Sierra *et al.,* 2005; Sierra *et al.,* 2025; Sierra *et al.,* 2016; Sierra *et al.,* 2016a; Sierra *et al.,* 2019]. Since 1954, in Cotaxtla experimental station there has been conducted research in corn crop to provide farmers technology to increase yield, improve economic benefits, and improve the supply of this basic grain.

The objectives have been: a] To develop varieties, hybrids, and synthetics with high yield potential and broad adaptation to the tropics, which minimize production risks with good ear coverage, an efficient archetype, and tolerance to lodging and major diseases; b] To improve the nutritional and industrial quality; c] To develop production technologies for grain and seeds; d] To produce basic and registered seed; d] To show farmers and technicians about the results obtained from corn research. This research pretends to elaborate an historical review on the genetic improvement of corn for the tropics, varieties, hybrids and synthetics of improved corn that have been used by farmers.

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Methodology

Localization. The area of influence the maize breeding program of the Cotaxtla Experimental station, is the humid and sub-humid tropical region of Mexico, which includes, according to García [2004], climate group A, which corresponds to the warm humid and sub-humid climates at altitudes ranging from 0 to 1200 meters above sea level [Aw0, Aw1, Aw2, Am and Af] and mainly covers the coastal region of the Gulf of Mexico and the Pacific Ocean.

Germplasm used. A compendium of genotypes generated for the tropical region in southeastern Mexico is compiled; specifically, in maize breeding, byproducts are generated such as open-pollinated varieties, synthetic varieties, and maize hybrids.

The genetic resources that have served as the basis for genetic improvement have been collections of landraces, the integration of broad-based maize germplasm composites [BGCs] that function as genetic repositories for line derivation or for recurrent selection, and advanced populations from the Tuxpeño maize strain.

Procedure. In corn breeding for the humid tropics of Mexico, population breeding, hybridization, and synthesis are used.

Population breeding. In corn crops exploits the additive portion of genetic variance present in populations and generates byproducts that are high-yielding, widely adapted, open-pollinated varieties. In hybridization, population breeding is also important because it offers the possibility of obtaining superior lines that, in turn, form better hybrid combinations. The principle of recurrent selection is to accumulate favorable genes for the trait being selected, and genetic variability is essential.

Hybrid development. In hybrids, genetic variance additivity deviation and heterosis, which are expressed in maize production, are exploited by crossing parents with relative genetic divergence [Reyes, 1985]. [Reyes 1971] used the heterotic pattern Humid Tropics x Dry Tropics in the formation of the first maize hybrids for the tropics, H-503 and H-507. Wellhausen [1978] suggested using the heterotic pattern between crystalline and dentate germplasm complexes.

When the breeder's objective is to separate divergent groups of advanced lines, it is advisable to use two lines that form a heterotic pair, i.e., with high ACE, as testers [Sierra *et al.,* 2004; Reyes, 1985; Hallauer and Miranda, 1981]. Lines with high GCA can also be identified with testers, which can be used in the development of synthetic varieties [Reyes, 1985]. When two heterotic groups of lines are identified, they can be useful in a recurrent reciprocal selection scheme [Reyes, 1985]. The use of testers for the selection of advanced lines, along with the evaluation of general and specific combining ability *per se*, represents an alternative methodological strategy for the generation of corn hybrids, since it allows for efficient cross-breeding of selected lines and thus achieves better hybrid combinations.

As a result of utilizing lines belonging to different heterotic groups, the single-cross hybrid H-513 and the trilinear hybrid LT154xLT155] LT156, defined for its official release as H-520, were identified as outstanding.

These hybrids offer advantages in seed production due to the use of the high-yielding single cross LT154xLT155 as the female parent [Sierra *et al.,* 2004].

Synthetic maize varieties. Synthetic maize varieties take advantage of the inherently good performance of inbred lines and their general combining ability to obtain high-yielding and widely adapted varieties [Marquez *et al.,* 1983]. They offer the advantage of greater adaptability. Furthermore, producers can use them for several planting cycles without affecting grain yield. Seed production is also easier [Reyes 1985].

Statistical methods. Statistical tools that have been used in corn breeding include randomized block designs, lattice designs, DMS significance tests, Duncan's t tests, combined analyses, genotype-environment interactions, and stability parameters. [Reyes, 1990; Andrés *et al.,* 2017; Andrés *et al.,* 2014; Sierra *et al.,* 2018]. In the characterization there were considered the variables suggested by SNICS [SNICS, 2014].

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Results and Discussion

Maize Hybrids and Varieties for the Tropics. During more than seven decades of continuous research in the maize program for the humid tropics, 16 hybrids, 6 open pollinated varieties and 5 synthetics from the 500 series have been released. These genotypes have been commercially accepted by farmers and which of them are currently in use the hybrids H-520, H-518, and the varieties and synthetics VS-536, V-537C, and V-540 adapted to the humid tropics at altitudes ranging from 0 to 1,200 meters above sea level [Table 1].

Box 1

Table 1

Hybrids and maize varieties released for the humid tropic in México 1952 a 2024

Genotype	Description	Registration number	Year of release
V-520C	Open pollinating Variety		1952
H-503	Double cross Hybrid		1955
H-507	Double cross Hybrid		1961
V-522	Open pollinating Variety		1975
VS-523A	Synthetic variety		1975
V-524	Open pollinating Variety		1975
H-510	Double cross Hybrid		1975
VS-525	Synthetic variety		1981
H-511	Single cross Hybrid		1981
V-530	Open pollinating Variety	MAZ-501-251104	1989
V-531	Open pollinating Variety		1990
V-532	Open pollinating Variety		1990
V-534	Open pollinating Variety	MAZ-502-251104	1990
VS-536*	Synthetic variety	MAZ-511-251104	1992
H-512	Double cross Hybrid	MAZ-428-030904	1993
H-513*	Single cross Hybrid	MAZ- 429-030904	1994
H-519C	High quality protein hybrid	MAZ-432-030904	2000
V-537C*	High quality protein variety	MAZ-503-251104	2000
V-556AC	High quality protein variety and yellow grain	MAZ-505-251104	2001
H-520*	Híbrido trilineal	MAZ-984-240209	2004
H-564C	High quality protein hybrid	MAZ-1018-260210	2010
H-518*	Trilinear hybrid	MAZ-2220-191120 3154 [Obtentor]	2023
V-540*	Open pollinating Variety	4849-MAZ-2644-301024/C	2024

* In current use

Source: Own elaboration

Progress of genetic improvement of maize

Regarding the progress of genetic improvement of maize for the tropics, the study reported by Sierra *et al.* [2005] is important.

This study evaluated the varieties, hybrids and hybrid parents generated in Campo Cotaxtla from 1952 to 2000 and reports significant progress up to that point. Subsequently, the work with the description of V-537C, H-520, H-518 and V-540 are reported too. [Sierra *et al.,* 2008 and Sierra *et al.,* 2025].

Varieties and synthetics. Regarding the progress of improvement for grain yield and agronomic characteristics in corn varieties from 1952 to 1991, in which there was significant progress from 1952 to 1975 and 1981 with varieties V-524 and VS-525, with significant achievements in grain yield, however, no less important was the lower plant and ear height in relation to the first varieties with which lodging risks were reduced; by 1989 there was an apparent decrease in yield with V-530; however, this variety released in 1989 was characterized as drought tolerant and recommended for areas with an Aw0 climate in the central region of Veracruz state mainly, an attribute that is not reflected in this evaluation. In 1992, the synthetic variety VS-536 was officially released, which recorded an increase in yield, but above all was well adopted by farmers in southeastern Mexico and by seed companies for its mass production and distribution [Sierra *et al.,* 2016].

Hybrids. For grain yield from 1955 to 2004. It is observed that the first hybrids released in 1955 and 1961, H-503 and H-507 respectively, registered good yield potential, and were adopted by farmers, particularly H-507, which was commercially distributed for more than 30 years [Reyes, 1971]. H-510, released in 1975, did not have major yield advantages and its use was limited. In 1981, H-511 was released, and although there was significant progress in the hybrid's yield, it was not commercially distributed, due, among other reasons, to the fact that it is a single-cross hybrid whose parents showed limitations in its maintenance and commercial production.

Hybrids H-513 [single cross] and H-512 [double cross], released in 1993 and 1994, were not commercialized as such because it coincided with the closure of the National Seed Producer [PRONASE] in Mexico. Based on work on testers with heterotic groups, and using outstanding single crosses as female parents, including H-513, and lines with good General Combining Aptitude as male parents, the combination of H-513 with the LT156 line was found to be outstanding and registered with the SNICS as H-520 [Sierra *et al.,* 2008]. It was adopted by farmers and seed producers. This hybrid shows good performance, adaptation to the tropics, and profitability in commercial seed production because it uses a high-yield single cross as a female parent [Sierra *et al.,* 2016].

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Yield and agronomic characteristics of commercially used corn genotypes. VS-536.

The synthetic variety VS-536 has a yield potential of 6.0 t ha^{-1} in commercial crops. It is well-adapted in southeastern Mexico. It is recommended for planting during the spring-summer agricultural season under rainfed conditions and during the fall-winter season under irrigated and tonalmil conditions. Regarding agronomic traits, VS-536 has an intermediate vegetative cycle with 52-55 days to flowering, 90 days to physiological maturity and 120 days to harvest, intermediate plant and ear height which allows it to adapt to different production systems and tolerance to lodging, it has good ear coverage and is tolerant to the main plant and ear diseases, it has a white grain, semi-dented texture, good nixtamalera and flour quality in accordance with international norms and standards which allows it to be well accepted in the market [Figure 1]

Box 2

Figure 1
VS-536, present white grain and dent texture
Source: Own elaboration

H-520. The H-520 hybrid has an intermediate plant and ear height, measuring 228 and 139 cm for each variable, respectively. During the spring-summer cycle, under rainfed conditions, the crop reaches physiological maturity in 90 to 100 days and can be harvested in 110 to 120 days. It is tolerant to lodging, with good plant and ear appearance and health, excellent ear coverage, with 14 rows and semi-dented white grain [Figure 2]. H-520 had the lowest percentages of plants with symptoms, the lowest severity, and the lowest percentages of ears with stunted damage [Sierra *et al.,* 2008].

Due to its ease and profitability in commercial seed production, the H-520 hybrid is the most widely used corn hybrid in southeastern Mexico.

Box 3

Figure 2
H-520 has a good appearance and health, white grain and dent texture
Source: Own elaboration

H-519C is a trilinear hybrid with high protein quality adapted to the tropical region. It has an intermediate cycle, with 55 to 56 days to male and female flowering, 90 to 100 days to physiological maturity, and 120 days to harvest. It has an intermediate plant height with an ear/plant height ratio of 0.53, which favors its tolerance to lodging. It presents good appearance and health of both plant and ear. The ear is cylindrical with 14 to 16 rows and has excellent ear coverage; the grain is white and crystalline in texture [Sierra *et al.,* 2019].

V-537C is an open-pollinated corn variety with a low plant and ear height and a cob/plant height ratio of 0.47, which confers tolerance to lodging. The cob is cylindrical with 14 rows; the kernel is white and has a semident texture [Sierra *et al.,* 2019].

V-556AC. It offers a potential in the forage industry and in balanced feeds, containing more lysine and tryptophan than regular corn. The most favorable tropical climates for its development are Aw0 and Aw1. It adapts to the tropical region of southeastern Mexico, at altitudes from 0 to 1000 meters above sea level, with yields of up to 6.0 t ha-1 of grain and 50 t ha-1 of forage. It has an intermediate plant and ear height, with an ear height/plant height ratio of 0.51, and is tolerant to lodging. Its grain is yellow and has a semi-crystalline texture with good ear coverage.

H-564C. This high-protein trilinear corn hybrid is adapted to the tropical region of southeastern Mexico and represents an alternative for increasing corn yields and improving consumer nutrition. This hybrid exhibits good yield and favorable agronomic characteristics: good ear coverage, good plant and ear appearance and health, and tolerance to stunting.

The ear is a white, semi-crystalline, cylindrical kernel with 12 to 14 regular rows, and its appearance is practically identical to that of regular corn.

V-540. In reference to grain yield across the seven environments of evaluation in both spring summer and fall Winter seasons under no irrigated conditions, it was found that V-540 registered 6.80 t ha^{-1} in grain, 16% more than the commercial check V-537C. The adaptability of this genotype permits to know the response to different environments defined by the clime, soil and agronomic management [Reyes 1990; Reyes, 1985, Andrés *et al.,* 2017; Sierra *et al.,* 2018]. Besides, V-540 registered a mean of forage yield across the five environments of evaluation of 41.83 t ha^{-1} of green forage for V-540, 14 % more than the check V-537C. Besides grain production V-540 is an alternative for producing forage for silage and using for animal feeding during the dry season in southeast of Mexico [Reyes 1990; Reyes, 1985, Andrés *et al.*, 2017; Sierra *et al.*, 2018]

Instead of agronomic traits, V-540 present intermediate height of plant and ear with 232 and 132 cm for each variable, respectively, a relation height of ear /height of plant of 0.56, it means, practically in the middle part, intermediate biological cycle with 52 to 54 days to flower, 80 to 90 days to physiological maturity and 120 days from sown to harvest during the spring summer season, present good husk cover, good plant and ear aspect and sanity, ears with 14 regular rows, cylindric shape, white grain and dent texture. V-540 is similar in biological cycle, higher in plant and ear height, better in ear aspect and sanity, good husk cover and ear rot than V-537C, open pollinating maize variety used as check [Márquez *et al.,* 1983; Reyes, 1985; Andrés *et al.,* 2014; Andrés *et al.,* 2016; Sierra *et al.,* 2016; Andrés *et al.,* 2017]

Box 4

Figure 3
V-540 present white grain and dent texture
Source: Own elaboration

Use of Improved Seed

Seed is undoubtedly the number one input in production, as it represents the yield potential and quality of the product. After the official release of a genotype, it is important to inform farmers, technicians, and seed producers about the benefits of the genetic material, as well as its performance and advantages for commercial seed production.

This requires having seed of high genetic, physiological, physical, and sanitary quality [Sierra et al., 2016]. INIFAP produces corn seed in basic and registered categories of varieties, hybrids, and their parents of outstanding genotypes adapted to the tropical region in southeastern Mexico. This seed is supplied to producers and/or companies that produce certified seed for commercial use by farmers. From 2007 to 2012, basic and registered seed of the normal corn genotypes VS-536, H-520 and high protein V-537C, H-519C and H-564C, white grain, and V-556AC, yellow grain were distributed to producer organizations and national seed companies for the production of certified seed, which made it possible to impact a total area of 643,959 hectares of commercial planting with these genotypes in southeastern Mexico during that period. VS-536 is the synthetic variety and H-520 is the hybrid, both with the highest use of improved seed in southeastern Mexico.

Conclusions

The tropical corn program has generated corn hybrids and varieties with agronomic and archetypal advantages, as well as advantages in commercial seed production.

There is outstanding corn germplasm that has been adopted by seed producers and groups, as well as by farmers in southeastern Mexico.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Sierra-Macías, Mauro: Corresponsable in the Project: "Mejoramiento genético y registro de variedades de maíz para el trópico bajo de México y sus nichos ecológicos" organization of the data and elaborating the information.

Ríos-Isidro, Clara: Asistant in the maize program Campo experimental Cotaxtla. Participation in the improvement of the maize variety V-540 organization of the data and elaborating the information.

Gómez-Montiel, Noel Orlando: Carried out the experiments and registration of variables and data recording in Iguala Guerrero sown and management of the seed plots organization of the data and elaborating the information

Barrón-Freyre, Sabel: Carried out the experiments and registration of variables and data recording in Huimanguillo Tabasco sown and management of plots, organization of the data and elaborating the information

Availability of data and materials

The data and the information that we present in this contribution are data of experiments conducted by INIFAP

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Abbreviations

INIFAP	National Institute of Forestry, Agriculture and Livestock Research
INIA	National Institute of Agriculture Research
SIAP	Service of agrifood and fishing information. Agricultural livestock and rural development ministry

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Article

Solar energy and agriculture: Revolutionizing water pumping in the field

Energía solar y agricultura: Revolucionando el bombeo de agua en el campo

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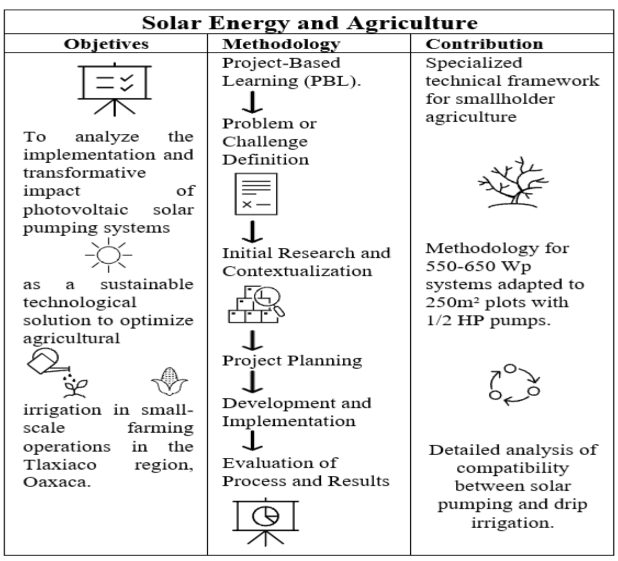
Abstract

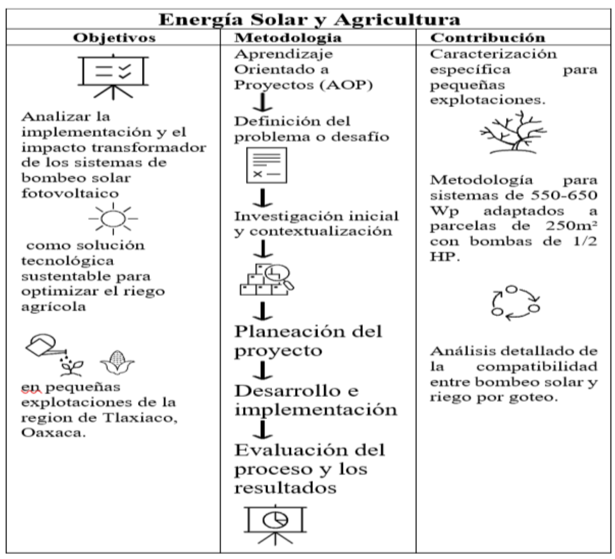
Solar pumping systems represent an innovative technological solution for small-scale agriculture in Tlaxiaco, Oaxaca. This study analyzes the implementation of photovoltaic systems for 250m² plots with 1/2 HP pumps and drip irrigation in the Mixteca Alta.



Agriculture, Solar energy, Irrigation

Resumen

Los sistemas de bombeo solar representan una solución tecnológica innovadora para la agricultura de pequeña escala en Tlaxiaco, Oaxaca. Este estudio analiza la implementación de sistemas fotovoltaicos para parcelas de 250m² con bombas de 1/2 HP y riego por goteo en la Mixteca Alta.



Agricultura, Energía Solar, Riego

Area: Advocacy and attention to national problems

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Introduction

In rural areas of Mexico, particularly in regions such as Tlaxiaco, Oaxaca, agriculture represents not only a fundamental economic activity but also a cultural and identity pillar [Altieri & Toledo, 2011]. However, Oaxacan farmers face critical challenges related to water access, an indispensable resource that is becoming increasingly scarce due to the effects of climate change and the variability of rainfall cycles in the Mixtec region [CONAGUA, 2022].

Paradoxically, Oaxaca, and specifically the Tlaxiaco region, has privileged solar potential. With radiation levels exceeding 5 kWh/m² daily during much of the year, this region possesses one of Mexico’s best solar resources, representing an invaluable opportunity to implement renewable technologies that harness this natural energy abundance [Energía Estratégica, 2019].

In this context, solar pumping systems emerge as a solution particularly adapted to the needs and realities of Tlaxiaco farmers. This technology allows harnessing the intense solar radiation characteristic of the region to power pumps that extract water from wells and aquifers, enabling crop irrigation without dependence on the unstable electrical grid or costly fuels.

For Mixtec communities, where the preservation of ancestral agricultural practices coexists with the need to adapt to new climatic and economic challenges, solar pumping represents not only a technological alternative but a tool for resilience and autonomy [Maka, Mehmood, & Chaudhary, 2022].

Photovoltaic systems for water pumping are gradually transforming the Oaxacan agricultural landscape, offering small and medium producers the possibility to maintain and even expand their production despite water and energy limitations [IRENA, 2022]. In Tlaxiaco, where a rich agricultural tradition, challenging climatic conditions, and extraordinary solar potential converge, this technology represents a silent revolution that promises to strengthen local food security, improve the economy of peasant families, and contribute to the environmental sustainability of one of Mexico's most bioculturally diverse regions [Secretaría de Agricultura, 2024].

This article explores how the integration of photovoltaic solar energy into water pumping systems is revolutionizing agricultural practices in Tlaxiaco, Oaxaca, opening new possibilities for more efficient, resilient, and sustainable agriculture in the heart of the Mixteca Alta.

Fundamentals of solar pumping systems

Solar pumping systems represent a comprehensive technological solution composed of various elements that work together to transform solar energy into mechanical work for water extraction and distribution [Singh, 2013]. In the context of Tlaxiaco, Oaxaca, where solar radiation reaches optimal levels during most of the year, these systems offer a particularly viable alternative [Kayar & Eskindir, 2016].

The main component of these systems are photovoltaic modules, responsible for converting solar radiation into electricity. In agricultural installations of the Mixteca Alta, monocrystalline or polycrystalline panels with power ratings ranging from 250W to 450W per module are recommended, depending on the crop's water requirements [Riaz, Imran, Alam, Alam, & Butt, 2021; Efiquality, 2024].

These panels should be installed with a preferably south-facing orientation and an inclination approximately equal to the local latitude [17°] to maximize energy capture throughout the year.

The pumping controller, also known as an inverter or driver, constitutes the "brain" of the system. This device adapts the electricity generated by the photovoltaic panels [direct current] to the characteristics required by the pump [which can operate with direct or alternating current, depending on the model]. Modern controllers incorporate protection functions against overload, dry running, and maximum power point tracking [MPPT], technology that allows optimal use of available energy even under variable radiation conditions, a characteristic frequent in mountainous areas like Tlaxiaco.

Pumps used in photovoltaic systems are specifically designed to operate with solar energy, and can be submersible [for deep wells] or surface-mounted [for rivers, lakes, or shallow wells].

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In the Oaxacan context, where many communities depend on wells with variable depths, helical submersible pumps have demonstrated outstanding performance due to their ability to operate with low radiation levels and their adaptability to energy fluctuations [INEEL, 2022]. These pumps can provide flow rates between 1,000 and 40,000 liters daily, sufficient to irrigate from small family plots to medium-sized extensions.

Pumps used in photovoltaic systems are specifically designed to operate with solar energy, and can be submersible [for deep wells] or surface-mounted [for rivers, lakes, or shallow wells]. In the Oaxacan context, where many communities depend on wells with variable depths, helical submersible pumps have demonstrated outstanding performance due to their ability to operate with low radiation levels and their adaptability to energy fluctuations [INEEL, 2022]. These pumps can provide flow rates between 1,000 and 40,000 liters daily, sufficient to irrigate from small family plots to medium-sized extensions.

Types of solar pumping systems

Direct solar pumping systems operate exclusively when solar radiation is available, using the energy generated in real-time by photovoltaic panels, which adjusts their performance according to solar intensity. In these systems, efficiency varies with radiation, and in regions like Tlaxiaco, where radiation availability is relatively stable during the dry season, they can represent an economical and low-maintenance solution [FAO, 2016]. However, their main limitation lies in the impossibility of operating during nighttime or very cloudy days, making it necessary to complement them with hydraulic storage.

Systems that incorporate batteries allow energy accumulation for later use, enabling pumping during periods without solar radiation. Although they offer greater operational flexibility, their implementation in Oaxacan agricultural contexts presents significant challenges: high costs, need for specialized maintenance, and shorter lifespan compared to other system components [SENER, 2023].

Nevertheless, in very isolated communities of Tlaxiaco with critical water needs, these systems can be justified, especially when combined with domestic electricity applications.

Hybrid systems integrate solar energy with complementary sources, such as diesel generators, electrical grid connections [when available], or even small wind turbines. This configuration offers maximum operational reliability, guaranteeing water supply regardless of meteorological conditions. In Mixtec territory, where electrical interruptions are frequent, solar-generator hybrid systems represent a viable alternative for farmers with high commercial value crops or critical water needs [León Gómez et al., 2024].

Operating principles and efficiency

The operation of a solar pumping system is based on the photovoltaic effect, through which the silicon cells of the panels generate electrical current upon receiving solar radiation. This electricity, once conditioned by the controller, powers the pump motor, which converts electrical energy into mechanical energy to drive the water.

The overall efficiency of these systems in real operating conditions in the Mixtec region of Oaxaca ranges from 3% to 7% [considering the conversion from solar radiation to effective hydraulic energy]. Although these figures may seem modest, they are economically viable due to the free and renewable nature of the energy source [Gevorkov et al., 2022].

Among the factors that determine efficiency in the specific context of Tlaxiaco are:

- The available solar radiation, which in this region reaches an average of 5.2-5.8 kWh/m²/day, surpassing the national average.
- The total manometric height [sum of the pumping depth and elevation height], a critical factor in a rugged topography like the Mixtec region.
- Hydraulic losses in pipes and fittings, which can be minimized through proper design.
- Water quality, which in some areas of Oaxaca has high sediment content, affecting pump performance and durability.

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Field studies conducted on solar pumping installations in communities of the Mixtec Alta region have shown that these systems can achieve payback periods of 3 to 5 years, compared to fossil fuel–based alternatives, when properly sized according to the farmer's specific needs and local conditions [Balenzategui & Hadj Arab, 1999; Odeh, Yohanis, & Norton, 2006].

Advantages of solar pumping in agriculture

Solar pumping offers substantial economic benefits for farmers in Tlaxiaco, especially in a context where energy price volatility directly impacts the profitability of agricultural operations [Chandel, Naik, & Chandel, 2015]. To understand the economic impact, let's consider a typical farm in the region with dimensions of 25 m × 10 m [250 m²], which uses a ½ HP pump [approximately 373 W] for 4 hours daily intermittently to power a drip irrigation system.

Under these specific conditions, a conventional pump connected to the electrical grid would consume approximately 1.5 kWh daily, resulting in a monthly expense of 350-450 Mexican pesos, considering the current agricultural rate in Oaxaca. If the same pump were operated with fossil fuels [diesel or gasoline], the monthly cost would rise to 600-750 pesos, not including additional maintenance and fuel transportation costs to remote areas. In contrast, a properly sized solar pumping system eliminates virtually all energy operational costs, resulting in annual savings of approximately 4,200–5,400 MXN when replacing conventional grid electricity and 7,200–9,000 MXN when replacing diesel-powered systems [Chandel, Naik, & Chandel, 2015; Gevorkov, Domínguez-García, & Trilla Romero, 2022].

For a plot with the mentioned characteristics, the required photovoltaic system would consist of approximately 550–650 Wp of installed power, with an investment cost ranging between 18,000 and 25,000 pesos, considering current market prices in Mexico [ANES, 2024].

Field studies conducted in communities of the Mixtec region of Oaxaca indicate that, under these conditions, the payback period is between 3.5 and 5 years when replacing conventional electricity, and between 2 and 3 years when replacing diesel or gasoline systems [Odeh, Yohanis, & Norton, 2006].

Particularly relevant for farmers in Tlaxiaco is the fact that, once this payback period is surpassed, the system continues to generate net savings for at least an additional 20–25 years, which corresponds to the estimated useful life of the photovoltaic panels [Branker, Pathak, & Pearce, 2011], while controllers and pumps may require replacement after 7–10 years.

The economic viability of these systems is enhanced by various government and non-government programs that facilitate their acquisition. The "Sustainable Agriculture Promotion Program" by SADER offers subsidies of up to 70% for small producers in highly marginalized areas like Tlaxiaco, significantly reducing the initial investment and shortening the payback period [SADER, 2024]. At the same time, organizations such as the Fondo para la Paz have implemented microcredit schemes specifically for solar technologies in Mixtec communities, with preferential rates and grace periods tailored to local agricultural cycles [Fondo para la Paz, 2022].

Environmental benefits

The implementation of solar pumping systems significantly contributes to climate change mitigation by reducing greenhouse gas emissions. In the specific case analyzed [1/2 HP pump, 4 hours daily], replacing conventional electricity would avoid the emission of approximately 235 kg of CO_2 annually, while replacing a diesel system would avoid up to 580 kg of CO_2 per year [INECC, 2023; Chandel et al., 2015].

The implementation of solar pumping systems at scale in Tlaxiaco could lead to an accumulated reduction of emissions greater than 2,000 tons of CO_2 annually at the municipal level. Solar pumping, especially when combined with drip irrigation systems like the one specified in this case, promotes more efficient water use.

Studies conducted in demonstration plots in the Mixtec Alta region show that this technological combination can reduce water consumption by up to 60 % compared to traditional gravity irrigation methods, thus alleviating pressure on local aquifers [Santini, Marini, & Benini, 2017].

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Additionally, by eliminating the risk of fuel spills associated with conventional pumps, solar systems help prevent soil and groundwater contamination, a particularly relevant issue in fragile ecosystems like those in the Mixtec region [CONAGUA, 2022].

A comparative life cycle analysis between conventional and photovoltaic pumping systems shows that the latter have a significantly smaller ecological footprint, even when considering the manufacturing processes and eventual disposal of components [Mansour et al., 2024].

The absence of moving parts in photovoltaic panels minimizes waste generation during their operation, while the high recyclability potential of components such as aluminum and silicon [over 90% in modern installations] enhances their sustainability profile.

Energy independence for farmers

In communities in Tlaxiaco, where power outages are frequent and can last for several days, especially during the rainy season, the energy independence provided by solar pumping systems represents a fundamental strategic value [CFE, 2023].

For farmers with crops sensitive to the lack of irrigation, this autonomy can mean the difference between losing or saving an entire harvest, which is critical for food security and family economic stability.

The documented case of the Mixtec community of San Miguel el Grande, where a community solar pumping system has maintained an uninterrupted water supply for irrigation for over five consecutive years, even during natural disasters that affected the regional power supply, illustrates the transformative potential of this technology in terms of agricultural resilience Food and Agriculture Organization of the United Nations [FAO], 2016.

The elimination of recurring payments for electricity or fuel allows farmers in Tlaxiaco to redirect limited economic resources toward other productive or family needs.

Surveys conducted among beneficiaries of solar pumping projects in the region reveal that approximately 65% of the resources previously allocated to energy are reinvested in productive improvements [such as improved seeds, infrastructure, etc.], while the remaining 35% helps meet basic needs like education and healthcare.

This release of economic resources, combined with the greater cost predictability offered by solar energy compared to the volatility of conventional energy prices, strengthens the long-term planning capacity of agricultural family units.

Adaptability to different production scales

One of the main advantages of solar pumping for the specific context of 250 m² plots with ½ HP pumps in Tlaxiaco is its inherent modularity. Systems can start with a basic setup of 2–3 panels [600–900 Wp], sufficient to meet immediate pumping needs [Chandel, Naik, & Chandel, 2015; Gevorkov, Domínguez-García, & Trilla Romero, 2022; Kayar & Eskindir, 2016], and later can be expanded by adding photovoltaic modules to incorporate new functionalities or increase productive capacity [Odeh, Yohanis, & Norton, 2006; Singh, 2013].

This feature is particularly valuable in a context where many farmers have limited resources for initial investment but foresee a path of gradual growth. Documented experiences in nearby communities such as Santa María Yucuhiti show how systems initially sized for individual plots have evolved into cooperative setups that supply multiple productive units, generating significant economies of scale.

The drip irrigation system specified in this case [intermittent operation for 4 hours] represents an optimal combination with solar pumping, as: The moderate flow rates required by drip irrigation are a perfect match for the operational characteristics of low-power solar pumps [½ HP], maximizing the efficiency of the system [Singh, 2013].

The inherent storage capacity of drip irrigation systems [through elevated tanks] naturally compensates for solar intermittency, ensuring water availability even during periods of inadequate radiation.

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The ability to schedule irrigation cycles during peak solar radiation hours [10:00 AM - 4:00 PM] allows for optimal use of the energy resource without the need for batteries, simplifying the system and reducing costs.

The guaranteed availability of water through solar pumping has facilitated productive diversification in numerous Mixtec communities. Farmers who traditionally relied on rain-fed crops such as corn and beans have been able to incorporate high-value commercial vegetables, ornamental flowers, and fruit trees, significantly improving their income

For the specific case of 250m² plots with drip irrigation systems powered by solar pumping, studies conducted by INIFAP document annual net income increases ranging from 45% to 80%, depending on the type of crop implemented and the marketing channels used [INIFAP, 2023]. This ability to diversify not only improves family economics but also contributes to the conservation of regional agrobiodiversity, which is essential for the cultural and ecological sustainability of the Mixtec Alta region [Altieri & Toledo, 2021].

Practical Implementation of Solar Pumping Systems

The proper sizing of a solar pumping system is the first critical step to ensure its efficiency and economic sustainability. In the specific context of Tlaxiaco, where small farms [approximately 25m × 10m = 250m²] with drip irrigation systems predominate, this process must consider multiple interrelated variables.

The calculation starts with the energy requirement of the selected pump. For the case studied, a 1/2 HP pump [approximately 373 watts] operating for 4 hours daily intermittently represents a daily energy consumption of approximately 1.5 kWh.

Considering the inherent losses in photovoltaic systems [DC-AC conversion, wiring, temperature, etc.] and a safety factor of 20%, the minimum required power for the photovoltaic array ranges between 550-650 Wp

Box 1

Figure 1
Researchers evaluating land for the implementation of a solar pumping system in a traditional plot in the Mixtec High region, Tlaxiaco

Own source

Water requirements vary significantly depending on the crop, development stage, and edaphoclimatic conditions. For traditional crops in the Mixtec region such as corn, beans, and squash, cultivated on plots of 250 m², studies conducted by INIFAP estimate average requirements of 4-6 liters/m²/day during critical stages, which represents a daily demand of 1,000-1,500 liters [INIFAP, 2023]. This volume can be easily met by a 1/2 HP pump powered by solar energy, which, under optimal conditions, can provide flows of 2,000-2,500 liters per day during the peak radiation period.

Box 2

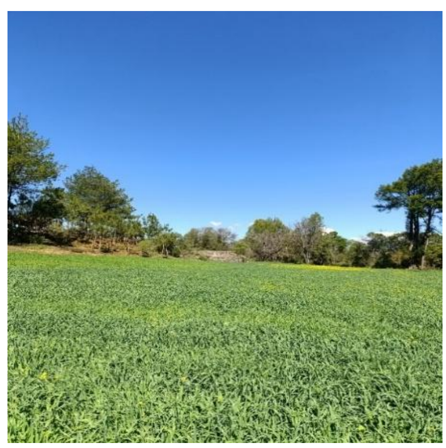

Figure 2
Traditional crop field [oat planting] in Tlaxiaco, where solar pumping systems help maintain agricultural productivity even during periods of water scarcity.

Own source

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Installation Considerations

The optimal location of the photovoltaic panels in the context of Tlaxiaco must consider both technical and practical factors. The ideal installation requires:

South orientation: Maximizes solar radiation capture throughout the day. For the specific latitude of Tlaxiaco [approximately 17° north], a tilt of the photovoltaic array between 15-20° from the horizontal is recommended, which helps optimize generation year-round

Absence of shadows: As shown in Figures 4 and 5, it is essential to install the panels in areas free from shadows during peak radiation hours [10:00-16:00]. Studies conducted in the region indicate that even partial shading can reduce system performance by up to 30-40%

Proximity to the extraction point: To reduce electrical conduction losses, the photovoltaic array should ideally be located within 20 meters of the pump in small-scale systems like those implemented in Tlaxiaco.

Support Structure: Support structures are often an underestimated but essential element to ensure the durability and performance of the system. In Tlaxiaco, where wind conditions can be significant during certain periods, metal structures with concrete anchors are recommended, designed to withstand wind speeds of up to 100 km/h.

As seen in Figures 3 and 4, contemporary installations use fixed tilted structures, generally made of galvanized steel profiles, which offer an excellent cost-benefit ratio.

Although solar trackers [structures that change their orientation to follow the movement of the sun] can increase energy production by up to 25%, their mechanical complexity and higher cost make them less suitable for small-scale agricultural applications in Mixtec communities.

Box 3

Figure 3
Solar panel installed for water pumping with optimal orientation to maximize solar radiation capture on an agricultural plot in Tlaxiaco.
Own source

The longevity of a solar pumping system largely depends on the implementation of proper protections and regular preventive maintenance. The main considerations include:

Electrical protections: Every system should include protection elements against surges, overloads, and lightning strikes, which are particularly important in the Mixtec region where thunderstorms are frequent during the wet season.

Protection against dry running: Modern controllers incorporate sensors that stop the pump when the water level falls below the minimum threshold, preventing costly mechanical damage.

Preventive maintenance: This includes regular cleaning of the panels [monthly panel cleaning, electrical inspections, pump checks] can increase system lifespan by up to 30% [Chandel, Naik, & Chandel, 2015].

Integration with existing irrigation systems

The effective integration of solar pumping with pre-existing irrigation systems presents both a technical challenge and an optimization opportunity. For typical plots in Tlaxiaco [250m²] with 1/2 HP pumps operating 4 hours daily in intermittent mode to supply drip irrigation systems, the following strategies are recommended:

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Hydraulic storage: The incorporation of elevated tanks [typically 1,000-2,500 liters for plots of this size] allows for the storage of water pumped during peak radiation hours to be used during optimal times for crop irrigation.

This solution, widely adopted in the Oaxaca Mixtec region, eliminates the need for batteries and significantly simplifies the system

Filtration systems: The implementation of appropriate filters between the pump outlet and the drip irrigation system prevents blockages, a common problem in areas where water contains high sediment levels, such as in some aquifers in Tlaxiaco [Hou et al., 2023].

Basic automation: Low-cost timers and solenoid valves allow for the scheduling of optimized irrigation cycles based on solar energy availability, maximizing the overall system efficiency. These devices are particularly recommended for farmers with complementary economic activities that limit their continuous presence on the plot.

Box 4

Figure 4

Detail of the photovoltaic array installation showing the wiring and connectors that ensure the efficiency and safety of the solar pumping system.

Own source

Cost estimation and financing

The implementation of a solar pumping system for a 250m² plot with a 1/2 HP pump in Tlaxiaco represents an initial investment that, while significant, offers attractive economic returns in the medium term. The typical cost structure includes:

Box 5

Table 1

Economic Analysis

Component	Approximate Cost [MXN]
Photovoltaic modules [600Wp]	9,000.00 - 12,000.00
Solar pump [1/2 HP]	6,500.00 - 8,500.00
Controller/inverter	3,000.00 - 4,500.00
Support structure	2,000.00 - 3,000.00
Storage system [1,500L tank] / In this case, a well with a depth of 6 meters was used.	3,500.00 - 5,000.00 / 0.0
Electrical and hydraulic accessories	1,500.00 - 2,500.00
Labor	3,000.00 - 5,000.00
Total Cost.	28,500.00 - 40,500.00

Own source with data from ANES [2024] and Valencia-Juárez & Méndez-Santiago [2022].

Financing Options: Access to financing often constitutes the main barrier to the massive adoption of solar technologies among small Mixtec farmers. Currently, there are various accessible alternatives for producers in Tlaxiaco: Government programs: The SADER, through the "Program to Promote Sustainable Agriculture," offers subsidies of up to 70% for the implementation of renewable energy technologies in small-scale production units in highly marginalized municipalities such as Tlaxiaco [SADER, 2024].

Microfinancing: Institutions such as the National Development Finance [FND] have developed specific credit products for sustainable technologies, with preferential rates [10-12% annually] and grace periods adjusted to agricultural production cycles [Secretariat of Economy, 2023].

Cooperative schemes: The formation of groups of producers to acquire systems of greater capacity that supply multiple plots has proven to be a successful strategy in Mixtec communities with limited resources, reducing costs by economies of scale by up to 25-30%

Private initiatives: Organizations such as the Peace Fund and the Mixtec Foundation have implemented innovative schemes that combine technical training, in-kind contributions from beneficiaries, and soft financing for the implementation of solar systems in indigenous communities of Oaxaca.

Campos-Donato, Eugenio Josué, Jiménez-Márquez, Omar, Oropeza-Tosca, Diana Rubí and Gómez-Álvarez José del Carmen. [2025]. Solar energy and agriculture: Revolutionizing water pumping in the field. ECORFAN Journal-Ecuador. 12[22]1-12: e21222112.
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The accumulated experience from projects implemented in the region demonstrates that the combination of these financing mechanisms, together with proper technical sizing of the system, ensures the economic sustainability of solar pumping even for farmers with very limited resources, transforming a technology initially perceived as a "luxury" into an accessible and profitable solution for the agricultural communities of the Upper Mixteca.

Conclusions

The implementation of solar pumping systems in the Tlaxiaco region of Oaxaca represents much more than a simple technological innovation; it constitutes a comprehensive transformation that impacts multiple dimensions of rural life in the Upper Mixteca.

Throughout this article, we have demonstrated how these systems, tailored to the specific needs of small-scale agricultural operations [25m × 10m] with 1/2 HP pumps and drip irrigation, offer viable solutions to structural problems that have historically limited regional agricultural development.

The detailed analysis of the technical components, economic benefits, environmental advantages, and practical considerations for implementation shows that solar pumping systems represent a mature technology adapted to the Mixtec context, capable of generating attractive returns on investment in relatively short periods [2-5 years].

Beyond the economic figures, the guaranteed access to water through renewable energy is enabling unprecedented productive diversification [Rodríguez Díaz et al., 2018], allowing Tlaxiaco farmers to introduce higher-value crops and reduce their vulnerability to adverse weather conditions.

Despite the undeniable documented benefits, the widespread adoption of solar pumping systems in Tlaxiaco still faces significant challenges that require coordinated attention. The financial barrier, although partially mitigated by various governmental and non-governmental support programs, continues to be a limitation for farmers with limited resources.

The consolidation and expansion of innovative financing schemes, especially those based on cooperative models and microcredits adapted to local production cycles, is fundamental to democratizing access to this technology [Escobar & Grubbauer, 2021].

In parallel, a technical knowledge gap persists that must be addressed through contextualized training strategies. Successful experiences in communities such as San Miguel el Grande and Santa María Yucuhiti demonstrate the importance of training processes that combine modern technical knowledge with traditional knowledge, respecting the cultural and linguistic particularities of the Mixtec communities.

Declarations

Conflict of interest

The authors declare no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this work.

Author contribution

Campos-Donato, Eugenio Josué: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization.

Jiménez-Márquez, Omar: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization.

Oropeza-Tosca, Diana Rubí: Conceptualization, Methodology, Software, Validation, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing.

Gómez-Alvarez, José del Carmen: Conceptualization, Methodology, Validation, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing.

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Availability of data and materials

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to the nature of the fieldwork and technical installation processes conducted in rural communities of Tlaxiaco, Oaxaca, detailed datasets, including technical configurations, energy performance logs, and economic evaluations, have been compiled.

These materials can be shared with researchers or institutions interested in replicating or scaling similar photovoltaic irrigation systems in comparable contexts.

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Abbreviations

CFE	Comisión Federal de Electricidad
CONAGUA	Comisión Nacional del Agua
FAO	Food and Agriculture Organization
FND	Financiera Nacional de Desarrollo
INECC	Instituto Nacional de Ecología y Cambio Climático
INEEL	Instituto Nacional de Electricidad y Energías Limpias
INIFAP	Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias
IRENA	International Renewable Energy Agency
MPPT	Maximum Power Point Tracking
Prot	Protección [used in context of electrical safety systems]
SADER	Secretaría de Agricultura y Desarrollo Rural
SENER	Secretaría de Energía
TecNM	Tecnológico Nacional de México.

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Administrative Management and Profitability of Pineapple Cultivation at the UMI-ITUG

Gestión Administrativa y Rentabilidad del Cultivo de Piña en la UMI-ITUG

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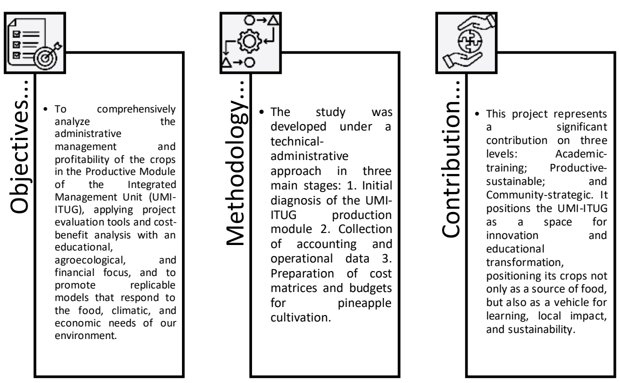
Abstract

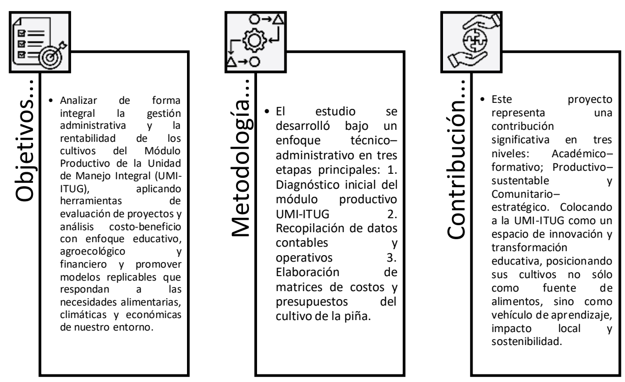
This study analyzes the cost-benefit ratio and administrative management of pineapple cultivation at the Production Unit of the Integrated Management Facility [UMI-ITUG], with the aim of evaluating its economic viability, operational efficiency, and sustainability. A study of production costs was conducted, considering inputs, labor, and infrastructure. Administrative management strategies were identified to optimize resources, improve planning, and enhance the competitiveness of the production unit. The conclusions emphasize the importance of efficient administrative management, the integration of agroecological practices, and the development of strategies to ensure the sustainability of the production unit.



Administrative management, Comprehensive management unit, Cost-benefit analysis

Resumen

El presente estudio analiza el costo-beneficio y la gestión administrativa del cultivo de piña en el Módulo Productivo de la Unidad de Manejo Integral [UMI-ITUG], con el objetivo de evaluar su viabilidad económica, eficiencia operativa y sostenibilidad. Se realizó un estudio sobre los costos de producción, considerando insumos, mano de obra e infraestructura. Se identificaron estrategias de gestión administrativa para optimizar recursos, mejorar la planificación y fortalecer la competitividad del módulo productivo. Las conclusiones destacan la importancia de una gestión administrativa eficiente, la integración de prácticas agroecológicas y el desarrollo de estrategias para garantizar la sostenibilidad del módulo productivo.



Gestión administrativa, Unidad de manejo integral, Análisis de costo-beneficio

Area: Promotion of frontier research and basic science in all fields of knowledge

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Introduction

In the context of the food, climate, and economic challenges facing rural communities, the management of agricultural production units with an educational focus represents a key strategy for ensuring food security, sustainability, and the comprehensive training of future professionals. The Integrated Management Unit [UMI-ITUG] at the TecNM Úrsulo Galván Campus is a space for training, research, and networking that seeks to strengthen viable and replicable production models.

The reengineering of the UMI-ITUG can be seen as a valuable tool for improving agricultural education, promoting sustainable practices, and fostering rural community development.

This study aims to analyze the cost-benefit and administrative management of pineapple crops in the UMI-ITUG Production Module. Key aspects such as profitability, sustainability, and operational efficiency will be addressed. This study proposes strategies for improving agricultural administration and production, presenting a comprehensive cost-benefit analysis and administrative management.

The initiative was launched in the context of strengthening agricultural production with a focus on sustainability, food security, and administrative efficiency, based on institutional objectives and local market demands.

This study identifies opportunities for improvement in management processes, resource optimization, and crop profitability, with an approach that integrates modern management tools and sustainability principles.

Methodology

The methodology used in this study consisted of three main stages:

1. Initial diagnosis of the UMI-ITUG production module
2. Collection of accounting and operational data
3. Preparation of cost matrices and budgets for pineapple cultivation.

Box 1

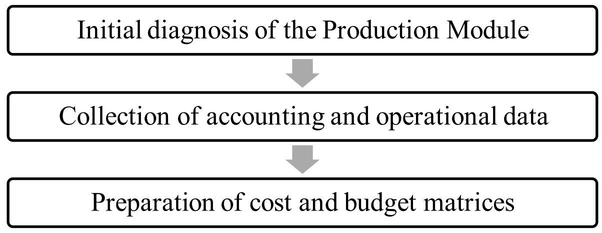

Figure 1

Methodology for research

Note: The image indicates the methodology used in the research.

Instrument to be used

The instruments used in this project were first an initial diagnostic report using a process map and a problem-opportunity matrix, and then, based on the information collected, a cost and budget matrix was created in Excel.

Box 2

Figure 2

Process map

Note: The figure indicates the process map to follow in the project planning stage

Box 3

Table 1

Problems-Opportunities Matrix

Ítem	Description	Guy	Impact	Frequency	Priority
1	Manual cost and yield records	Problem	High	Loud	1
2	Lack of formal watering schedule	Problem	Middle	Loud	2
3	Packaging processes without quality standardization	Problem	Middle	Media	4
4	High costs of agrochemicals per isolated purchase	Problem	High	Media	3
5	Unhedged market price variability	Problem	High	Casualty	5
6	Implementación de software de gestión de agronegocios	Opportunity	High	Media	2
7	Grouping of purchases for discount on inputs	Opportunity	Middle	Loud	1
8	Good Agricultural Practices [GAP] Training	Opportunity	High	Media	3
9	Using Moisture Sensors to Optimize Irrigation	Opportunity	Middle	Media	4
10	Development of direct-to-consumer sales channels	Opportunity	High	Casualty	5

Note: The figure indicates a matrix of Problems-Opportunities detected in the diagnosis.

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Results

Quantitative and qualitative information was collected through internal accounting records, operating logs, and physical files. Accurate data was collected on direct costs [agricultural inputs, fertilizers, seeds, agrochemicals], indirect costs [infrastructure maintenance, energy, water], and labor costs.

Based on the financial and operational information obtained, cost matrices were constructed detailing investment requirements and operating expenses.

The results are as follows:

Box 4

Production Costs for 1.5 Hectares of Pineapple

Activity and/or Product	U. M.	Quantity	Unit Cost	Total Cost
Plant Purchase				
Pineapple Plant	plant	60,000.00	$ 3.00	$ 180,000.00
Freight	trip	5.00	$ 500.00	$ 2,500.00
Newspaper	newspaper	9.00	$ 150.00	$ 1,350.00
				$ -
Subtotal				**$ 183,850.00**
Preparation of the land				
Chapeo	newspaper	12	$ 120.00	$ 1,440.00
Incorporation of harvest residues	newspaper	5	$ 120.00	$ 600.00
Liming	newspaper	5	$ 120.00	$ 600.00
Fallow	service	2	$ 800.00	$ 1,600.00
Tracking	newspaper	5	$ 120.00	$ 600.00
Levelling	newspaper	6	$ 120.00	$ 720.00
Tracing paths	newspaper	10	$ 120.00	$ 1,200.00
Construction of beds and drains	newspaper	14	$ 120.00	$ 1,680.00
Fallow	service	4	$ 800.00	$ 3,200.00
Collection and preparation of vegetative ma	newspaper	6	$ 120.00	$ 720.00
Subtotal				**$ 12,360.00**
Crop preparation				
Sowing	newspaper	8.00	$ 120.00	$ 960.00
Weed Control	newspaper	10.00	$ 120.00	$ 1,200.00
Floral Induction Treatments	newspaper	6.00	$ 120.00	$ 720.00
Irrigation	newspaper	12.00	$ 120.00	$ 1,440.00
Fertilization	newspaper	12.00	$ 120.00	$ 1,440.00
Pest Control	newspaper	10.00	$ 120.00	$ 1,200.00
Phytosanitary management	newspaper	12.00	$ 120.00	$ 1,440.00
Subtotal				**$ 8,400.00**
Fertilization and pest and disease control				
Ammonium Sulfate	bulto	9	370	$ 3,330.00
Urea 50 kg	bulto	9	480	$ 4,320.00
Dap 18-46-00	bulto	9	680	$ 6,120.00
Fertipiña	kg	15	135	$ 2,025.00
Poliquel zn	l	12	92	$ 1,104.00
Poliquel fe	l	12	92	$ 1,104.00
Paracuat	l	5	98	$ 490.00
Hortan 45	l	6	137	$ 822.00
Vydate	l	8	386	$ 3,088.00
Aliette	kg	6	769	$ 4,614.00
Carbide	kg	5	39	$ 195.00
Diazinon	l	22	190	$ 4,180.00
Raizal	kg	12	148	$ 1,776.00
Dimetoato	l	6	145	$ 870.00
Hyvar	l	6	1220	$ 7,320.00
Subtotal				**41,358.00**
Harvest				
Harvest	newspaper	50.00	$ 120.00	$ 6,000.00
Fruit hauling	newspaper	20.00	$ 120.00	$ 2,400.00
Transport	service	8.00	$ 500.00	$ 4,000.00
Subtotal				**12,400.00**
		TOTAL 1.5 HECTAREAS		**$ 258,368.00**

Figure 3

Production costs.

Note: The figure indicates the production costs for an area of 1.5 hectares

Box 5

PINEAPPLE PRODUCTION

INVESTMENT BUDGET

CONCEPTS	UNIT	QUANTITY	UNIT COST	AMOUNTS	FAPPA	PARTNERS	TOTAL
FIXED ASSET							
VEGETATIVE MATERIAL	PIECE	60000	3	$ 180,000.00	$ 180,000.00		$ 180,000.00
PUMPS	PIECE	6	1220	$ 7,320.00	$ 7,320.00		$ 7,320.00
COAS	PIECE	6	390	$ 2,340.00	$ 2,340.00		$ 2,340.00
MACHETES	PIECE	6	82	$ 492.00	$ 492.00		$ 492.00
GLOVES	PIECE	6	25	$ 150.00	$ 150.00		$ 150.00
WHEELBARROWS	PIECE	6	980	$ 5,880.00	$ 5,880.00		$ 5,880.00
BARS	PIECE	6	410	$ 2,460.00	$ 2,460.00		$ 2,460.00
TERRAIN	HECTARES	1.5	$ 25,000.00	$ 37,500.00		$ 37,500.00	$ 37,500.00
Subtotal				**$ 236,142.00**	**$ 198,642.00**	**$ 37,500.00**	**$ 236,142.00**
DEFERRED ASSETS							
Profiling and technical assistance	Budget	1	$ 28,800.00	$ 28,800.00	$ 28,800.00		$ 28,800.00
Subtotal				**$ 28,800.00**	**$ 28,800.00**	**$ -**	**$ 28,800.00**
WORKING CAPITAL							
Preparation of the land	Budget	1	$ 12,360.00	$ 12,360.00		$ 12,360.00	$ 12,360.00
Crop preparation	Budget	1	$ 8,400.00	$ 8,400.00		$ 8,400.00	$ 8,400.00
Fertilization and pest and disease control	Budget	1	$ 41,358.00	$ 41,358.00	$ 41,358.00	$ -	$ 41,358.00
Harvest	Budget	1	$ 12,400.00	$ 12,400.00		$ 12,400.00	$ 12,400.00
Subtotal				**$ 74,518.00**	**$ 41,358.00**	**$ 33,160.00**	**$ 74,518.00**
TOTAL				**$ 339,460.00**	**$ 268,800.00**	**$ 70,660.00**	**$ 339,460.00**

Figure 4

Investment Budget at a scale of 1.5 Has.

Note: The figure indicates the investment budget for pineapple cultivation on an area of 1.5 hectares

It is important to emphasize that the investment budget is designed for a 1.5 hectare plot of land, as the land available within the ITUG facilities is inefficient for large-scale cultivation. However, the actual data was collected from a local producer who has the ideal size for pineapple cultivation and a positive return.

Conclusions

Proper administrative management in an agricultural production unit allows for the generation of not only economic value, but also social and educational value. The cost-benefit analysis of pineapple cultivation demonstrated the viability of both systems under local conditions, with pineapple being the most beneficial for its financial performance.

The financial and administrative analysis carried out on pineapple cultivation in the productive module of the UMI-ITUG allows us to conclude that the project presents a highly favorable profitability from the economic-financial perspective, as well as from the operational management perspective.

With an Internal Rate of Return [IRR] of 48.39%, well above the 10% discount rate used, and a Net Present Value [NPV] of $1,619,833.10, it is demonstrated that the cash flows generated far exceed the initial investment, validating the viability of the project in the short and medium term. Furthermore, the Benefit-Cost Ratio of 2.09 indicates that for every peso invested, a return of $2.09 is obtained, reflecting efficient resource management and a sustainable cost structure.

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Recommendations

From an institutional perspective, the study reaffirms the value of integrating applied research with training processes, actively involving students, technicians, and managers, which fosters a model of participatory governance and continuous improvement. It is recommended to continue monitoring key indicators, strengthen the systematization of field data, and scale the model to other priority crops, promoting the economic and social sustainability of the UMI-ITUG.

It is also recommended that the area be 1.5 hectares for profitability, as the UMI-ITUG currently only has 2,500 square meters. This is sufficient for learning scenarios but not economically viable.

In every company as part of its administrative management, The implementation of biannual administrative audits allows to guarantee effective control over organizational processes. This not only contributes to improving the company's performance and competitiveness, but also drives a culture of continuous improvement and operational excellence. [Balderrabano-Briones, Martínez-Gutiérrez, & Pérez-Garmendia, Administrative audit of the administrative office of a multinational industrial, 2025].

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Balderrabano-Briones, Jazmín: Writing the draft version of the manuscript

Utrera-Velez, Youssef: Carefully proofread and revise the final version following the format and guidance;

Rodriguez-Agustin, Griselda: Fill out the required forms to submit the article

Soria-Vazquez, Reyna Susana: Modify the manuscript according to the Evaluation made by the reviewers

Availability of data and materials

The data obtained in the investigation are available in the final report of the administrative authority.

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Abbreviations

ITUG	Úrsulo Galván Technological Institute
TecNM	National Technological Institute of Mexico
IRR	Internal Rate of Return
UMI	Integrated Management Unit
UMI-ITUG	Integrated Management Unit of the Úrsulo Galván Technological Institute
NPV	Net Present Value

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Use of QR codes in school laboratories

Uso de códigos QR en laboratorios escolares

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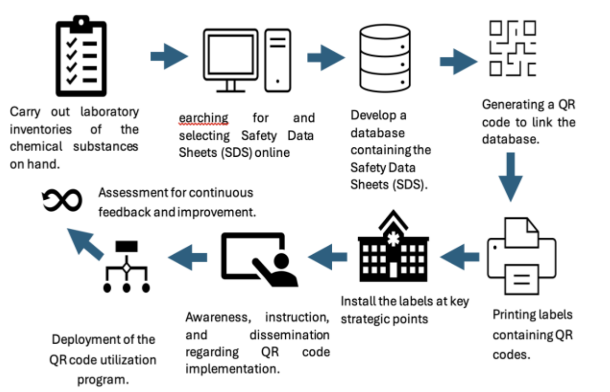
Abstract

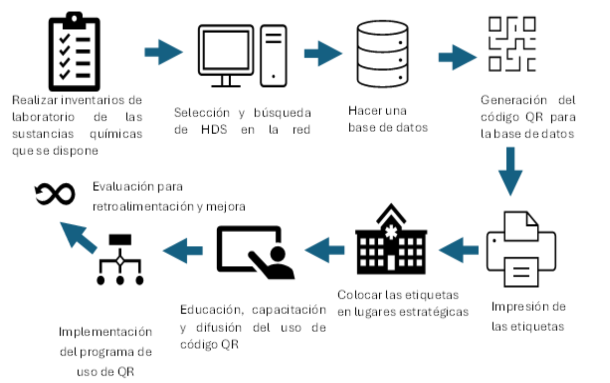
Chemical substances pose a risk that must be properly managed in teaching laboratories. Therefore, Safety Data Sheets [SDS] are key documents that assist personnel handling these substances in identifying characteristics, hazards, required protective equipment, and disposal methods; however, timely access to them may be limited. The process includes identifying substances, searching for and selecting SDS from official sources, creating a digital database, and generating QR codes using free platforms. Their strategic placement in the laboratory, along with staff training, ensures their effectiveness. Among the advantages are the low cost, ease of implementation, continuous information updates, and the promotion of responsible technology use in educational settings. This proposal strengthens safety, a preventive culture, and autonomous learning in university laboratories.



Laboratory safety, Preventive culture, Educational technology

Resumen

Las sustancias químicas representan un riesgo que debe gestionarse adecuadamente en los laboratorios de docencia; por ello, las hojas de datos de seguridad [HDS] son documentos clave para auxiliar al personal que maneja estas sustancias para reconocer características, peligros, equipo de protección necesario y métodos de disposición; su acceso oportuno puede estar limitado. El proceso incluye la identificación de sustancias, búsqueda y selección de HDS en fuentes oficiales, creación de una base de datos digital y generación de códigos QR mediante plataformas gratuitas; su colocación estratégica en el laboratorio y la capacitación del personal aseguran su efectividad. Entre las ventajas destacan el bajo costo, la facilidad de implementación, la actualización constante de la información y el fomento del uso responsable de tecnología en contextos educativos. Esta propuesta fortalece la seguridad, la cultura preventiva y el aprendizaje autónomo en los laboratorios universitarios.



Seguridad en laboratorios, Cultura preventiva, Tecnología educativa

Area: Promotion of frontier research and basic science in all fields of knowledge

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Introduction

On a daily basis, a number of chemicals are handled in higher education laboratories that represent a potential risk if the necessary knowledge and precautions are not taken to handle them; therefore, the daily work relies on consulting safety data sheets because it is a document that describes the chemical characteristics, hazards, protective measures, first aid and proper disposal in relation to the chemical in question.

Unfortunately, safety data sheets are not always readily available, available or accessible to the personnel who require them in a timely manner, especially when time is of the essence and the response must be quick and accurate.

In this situation, the digitisation of documents necessary for the proper management and handling of chemicals is well coupled with the use of mobile technologies to provide effective solutions; In this sense, the incorporation of QR codes on reagent bottles or for the disposal of chemicals, on laboratory shelves and in strategic places in the laboratory offers an operational advantage as these codes are scannable on any mobile device such as phones and tablets, then redirect the user to a database that concentrates the safety data sheets available at that location, this significantly improves informed decision making.

The use of QR codes

QR stands for "Quick Response" and is a type of two-dimensional barcode that stores information of different types such as redirects to websites for links, documents or PDF files; the reading is almost instantaneous so it facilitates access and search, and is available to anyone with a mobile device that can read them.

Thus, this technology can be used in the context of laboratory work because it can be linked directly to the safety data sheet or a database that concentrates them and allows them to be searched immediately.

Box 1

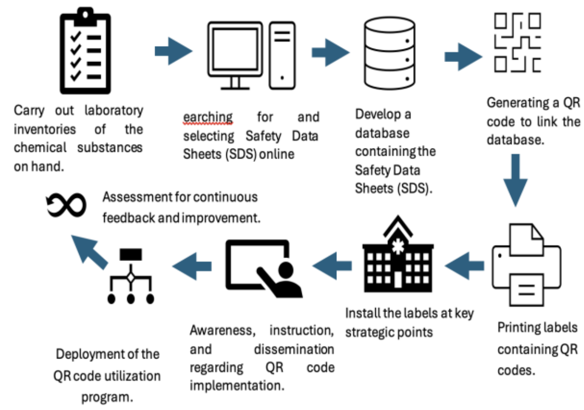

Figure 1

Process Flowchart for the use of QR Codes to access Safety Data Sheets [SDS] in teaching laboratories.

Source: Own elaboration

Implementing QR codes is relatively easy [Figure 1]. To do so, you must first select the priority reagents, identifying the substances that require special attention due to their risk in order to prioritize them. Then, you begin searching for the safety data sheets on official websites, refine and select the information, Next, download, store, and create a database with this information to link it to the QR codes created on free platforms such as QR Code Generator.

The codes are printed in strategic locations for consultation, and staff are trained on how to consult the safety data sheets. As with any program, it is recommended to constantly monitor its function and seek opportunities for continuous quality improvement.

Advantages of using QR codes in teaching laboratories

There are several advantages to implementing QR codes for accessing safety data sheets in teaching laboratories. The first notable advantage is that it allows quick access to safety information. Another advantage is that it reduces errors and risks because the information is pre-selected by safety experts and made available to all laboratory staff. Another notable advantage is education in the responsible use of technology by promoting a culture of searching, consultation, and active verification of scientific information, which improves individual and collective responsibility.

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This leads to constant updating because, unlike printed sheets, QR codes link to online documents that are periodically updated by the laboratory safety committee. Undoubtedly, a feature of this proposal is the low cost of implementation.

Generating QR codes is free and can be easily integrated into laboratory signage.

Box 2

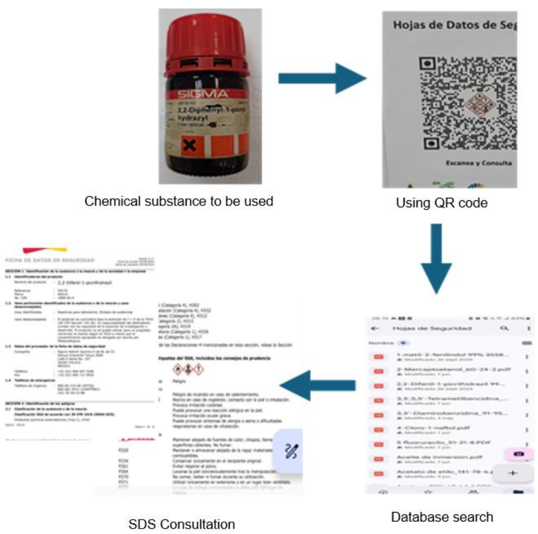

Figure 1

Example of the use of QR codes to access safety data sheets for a chemical in the teaching laboratory

Source: Own elaboration

Safety Data Sheets

The acronym HDS is commonly used for safety data sheets, but these documents are also known by their English acronyms SDS [Safety Data Sheets] and MSDS [Material Safety Data Sheets] according to international references used in different regulations. HDS are official documents that provide sufficient information about a chemical substance or mixture to ensure the safe use and handling of chemicals in both academic and industrial settings.

They are regulated by international standards, including the Globally Harmonized System of Classification and Labelling of Chemicals, which has been adopted by the UN and national agencies such as the US Occupational Safety and Health Administration [OSHA], REACH in Europe, and NOM-018-STPS-2015 in Mexico, which establishes the harmonized system for the identification and communication of hazards and risks posed by hazardous chemicals in the workplace.

The importance of MSDSs is that they must contain 16 mandatory sections that provide information on the characteristics of the substance and its handling, as they not only identify the product by its chemical name and recommended uses, but also identify the hazards by classifying them according to their CRETIB characteristics [corrosive, reactive, explosive, toxic, flammable, and biologically infectious].

They include hazard pictograms according to the Globally Harmonized System, warnings, and risk and precautionary statements. They also detail first aid procedures in case of inhalation, ingestion, or contact with skin and eyes, as well as the type of fire extinguisher to use and recommendations for firefighters.

An important aspect of MSDSs is that they include information for the proper handling and storage of substances because they describe safe conditions for use and recommendations for storage [temperature, ventilation, and, most importantly, the existence of incompatibilities between substances], as well as chemical stability, hazardous reactions, and incompatible conditions and materials.

This is complemented by instructions on the personal protective equipment [gloves, goggles, and masks] that must be used during handling.

An important point about the toxicological information on chemicals in MSDSs is that it is not limited to describing the toxicity to humans who are exposed to them, but also presents data on environmental toxicity such as persistence, degradability, and bioaccumulation. It also contains considerations for proper disposal and safe methods for disposing of the product or its packaging, all in accordance with applicable international regulations.

In the educational setting of university teaching laboratories, SDSs allow personnel involved in the use and handling of chemical reagents to recognize the risks of substances before handling them, make decisions based on relevant information for the use of personal protective equipment, and act correctly, efficiently, and promptly in the event of an accident or spill.

Mex-Álvarez, Rafael Manuel de Jesús, Yánez-Nava, David, Guillen-Morales, María Magali and Chan-Martínez, Roger Enrique. [2025]. Use of QR codes in school laboratories. ECORFAN Journal-Ecuador. 12[22]1-4: e41222104.
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Conclusions

Laboratory safety is an essential element in everyday work, which is why any tool that promotes and strengthens it should be used; The use of QR codes in university teaching laboratories is a free, simple, and easy tool that contributes to the autonomy and modernization of university teaching.

It requires a minimal investment of time and resources [human and material] but achieves a significant improvement in the culture of prevention and in the teaching-learning process of the sciences.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Contribution of the authors

Mex-Álvarez, Rafael Manuel de Jesús: Idea and conceptualization, Literature review, Review and adjustments, Oversight and final validation.
Yanez-Nava, David: Idea and conceptualization and final validation.

Guillen-Morales, María Magali: Literature review, Review and adjustments.

Chan-Martínez, Roger Enrique: Literature review, Review and adjustments.

Abbreviations

USA	United States
HDS	Safety Data Sheet
UN	United Nations
MSDS	Material Safety Data Sheets
QR	Quick Response
SDS	Safety Data Sheets

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Background

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Article

Preparation and shelf life evaluation of a fermented hot sauce based of costeño chili peppers *Capsicum annuum* L. from Tabasco, Mexico

Elaboración y evaluación de vida de anaquel de una salsa picante fermentada a base de chile costeño *Capsicum annuum* L. de Tabasco, México

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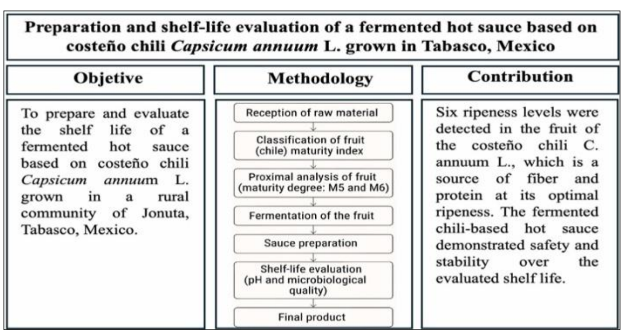
Abstract

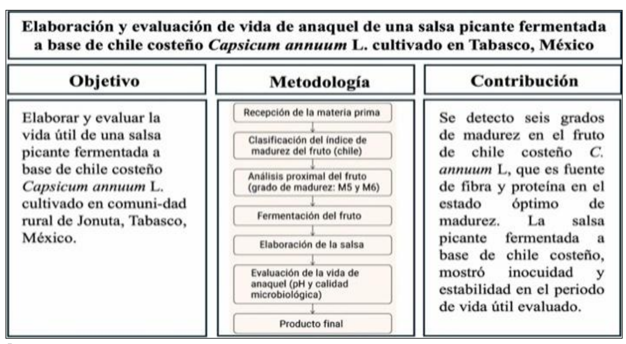
The objective of this research was to develop and evaluate the shelf life of a fermented hot sauce based of chili peppers *Capsicum annuum* L. grown in a rural community in Jonuta, Tabasco, Mexico. The different degrees of ripeness of the peppers were determined, and a proximate analysis was performed on the fruits at optimal ripeness. A fermented hot sauce was produced and its shelf-life [pH and microbiological] was evaluated. The chili peppers *Capsicum annuum* L fruit at optimal maturity [M5 and M6] proved to be a considerable source of total dietary fiber [7.96%] and total protein [5.89%], confirming its potential as a raw material in the production of a fermented hot sauce. which showed pH stability and the absence of microorganisms [aerobic mesophiles, total coliforms, molds, and yeasts] during six months of storage.



Maturity Index, Proximate Analysis, Emulsion

Resumen

El objetivo de esta investigación fue elaborar y evaluar la vida de anaquel de una salsa picante fermentada a partir de chile costeño *Capsicum annuum* L cultivado en una comunidad rural de Jonuta, Tabasco México. Se determinó los diferentes grados de madurez del fruto de chile costeño, se realizó el análisis proximal a los frutos en estado óptimo de madurez. Se elaboró una salsa picante fermentada y se evaluó la vida de anaquel [pH y microbiológicos]. El fruto del chile costeño *C. annuum* L en estado óptimo de madurez, mostró ser fuente considerable de fibra dietética total [7.96%] y proteína total [5.89%], lo que confirmó su potencial como materia prima en la elaboración de una salsa picante fermentada; misma que mostró estabilidad a pH y ausencia de microorganismos [mesófilos aerobios, coliformes totales, mohos y levaduras] durante los seis meses de almacenamiento.



Índice De Madurez, Análisis Proximal, Emulsión

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

One of the first crops to be domesticated was the chili peppers *Capsicum* spp., which includes five species: *C. annuum* var. *annuum*, *C. chinense*, *C. frutescens*, *C. baccatum* var. *pendulo*, and *C. pubescens* [Liu et al., 2023]. In Mexico, the cultivation and consumption of this fruit is both economically and socioculturally significant, with *Capsicum annuum* L. being the most important species, giving rise to a wide variety that differ in shape, color, size, and level of spiciness [different concentrations of capsaicin] [Aguirre-Mancilla et al., 2017].

The fruit of *Capsicum* spp. peppers contain different concentrations of pigments such as chlorophyll, anthocyanin, lutein, vitamin C [up to 200 mg/100 g], tocopherols [vitamin E: 16 mg/100 g] [Wahyuni et al., 2011], carotenoids [provitamin A], flavonoids, minerals [iron and calcium], and phenolic compounds such as luteolin, quercetin, and capsaicinoids, which are attributed with health benefits [Wahyuni et al., 2013], such as antioxidant, urinary disorders, antimicrobial, analgesic, among others [Hernández-Pérez et al., 2020].

In the state of Tabasco, total green chili peppers production—including all varieties—reached a volume of 3,472.71 tons [t] in 2022. The municipalities with the highest production were Macuspana [744.35 t], Jonuta [345 t], Balancán [506.35 t], Emiliano Zapata [516.4 t], Centro [446.6 t], Centla [412.28 t], and Tenosique [345 t] [SIAP, 2023]. However, to date, there are no statistical data on the production of costeño chili peppers C. *annuum* L., which is a major crop [between half and two hectares] for rural families in the municipality of Jonuta, Tabasco.

Those who sell their harvest of dried chili peppers [sun-dried] to intermediaries generally do so at a low price [$250 to $350 MXN]. Prolonged storage of dried chili peppers in inadequate conditions can cause deterioration or contamination by mold, generating undesirable flavors and odors.

To reduce these losses, it is recommended to apply processing and preservation methods—such as making sauces, moles, or pickles—that extend the product's shelf life and add value, improving its profitability.

Alcoholic fermentation is an ideal preservation biotechnology for products such as fruits and vegetables [Andreu & Saavedra, 2022], including chili peppers. This preservation method extends the shelf life from 2-3 days to more than 12 months, improving the nutritional properties of the food. This process generates an ethanol-rich environment and can lower pH, which inhibits pathogenic microorganisms or spoilage, ensuring microbiological safety. In addition, it promotes the development of bioactive compounds [antioxidants and antimicrobial peptides], enhancing functional properties such as those of chili peppers *Capsicum* spp. and creating a differentiated product with greater added value [Gupta et al., 2022].

Alcoholic fermentation is mainly carried out by *Saccharomyces cerevisiae* [Fleet, 2008]; a single- celled fungus 5-10 μm in diameter, with an ovoid morphology, tolerant to ethanol [up to 15-18% v/v] and capable of fermenting a wide variety of sugars, resistant to osmotic stress [22-24%] [Pretorius, 2000] and producing limited amounts of undesirable secondary metabolites.

However, temperatures above 33-35 °C can cause the fermentation process to be interrupted and promote bacterial contamination [Santamaría et al., 1995]; similarly, high sugar concentrations can induce cell plasmolysis. It is therefore essential to adjust the conditions of the medium to ensure an efficient and safe fermentation process. On the other hand, seasoning products such as hot sauces require organic additives to maintain the emulsion, which is why xanthan gum is used in the food industry as an emulsifier, stabilizer, and thickener in a wide range of products. Its ability to form viscous and stable solutions allows the mixture between aqueous and oily phases to remain homogeneous, preventing the separation of ingredients during storage [Costa et al., 2014]. Xanthan gum is an extracellular polysaccharide produced by fermentation by the gram-negative bacterium *Xanthomonas campestris* [García-Ochoa et al., 2000].

Its chemical structure consists of a main chain of β-D-glucose with side chains of mannose and glucuronic acid, which give it exceptional rheological properties such as high viscosity at low concentrations, thermal stability to temperature variations [high solubility in cold or hot water], resistance to pH variations and salt concentration [Chaturvedi et al., 2021].

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It also has pseudoplastic properties that make it an ideal hydrocolloid for food applications [BeMiller & Whistler, 2009]. Its molecular weight ranges from 1 to 3 million daltons, which, together with its branched structure, gives it the ability to form highly viscous solutions at very low concentrations [0.1% to 0.5%].

Therefore, xanthan gum significantly improves the stability of oil-in-water emulsions, especially when combined with other emulsifiers or proteins [McClements, 2004]. This property is particularly important in complex food systems such as hot sauces, where the presence of suspended solid particles, pH variations, and the presence of salts can affect the stability of the emulsion.

In line with the above, the objective of this research was to develop and evaluate the shelf life of a fermented hot sauce based of chili peppers *Capsicum annuum* L. grown in a rural community in Jonuta, Tabasco, Mexico.

Methodology

Samples of costeño chili peppers *C. annuum* L [4.5 Kg] at different stages of physiological maturity [harvested in March-April 2024] were obtained from a producer in the rural community of El Bajío [Longitude: *-91.915117,* Latitude: *17.*906274], Ranchería [R/a], Boca de San Gerónimo, Jonuta, Tabasco, Mexico [Figure 1]. The ranch is located 1 km from the Usumacinta River, 21 Km from Villa Chablé, Emiliano Zapata, Tabasco, Mexico.

Box 1

Figure 1

Location of El Bajío Ranch. Boca de San Gerónimo, Jonuta, Tabasco, Mexico.

Source: Satellite image of google map.

Maturity index and proximal analysis of the costeño chili peppers

The research began with the classification of chili fruits according to their degree of maturity [skin color] [García-Gaytán et al., 2017]. The color code was located on the Color-hex palette [2010-2024]. Proximal analysis was performed on the fruit at optimal physiological maturity; the concentration of moisture, ash, total fat, crude fiber, and total protein on a dry basis [B.S] was evaluated, except for moisture [AOAC, 1990].

Preparation of the hot sauce

Samples of costeño chili peppers *C. annuum* L., fresh and at optimal ripeness, were dehydrated in a digital dehydrator [Ivation, 110 Volts, 35 to 70ºC] with air circulation at 70ºC for 6 hours; they were then pulverized in a food processor [Oster® classic 2-speed blender].

Preparation of the must to be fermented: 50 g of chili powder was weighed, placed in a stainless-steel container [pot], 400 mL of purified water was added, and it was pasteurized at 75°C for 10 min. Once the time was up, the mixture was placed in a 1000 mL glass bioreactor, and 25 or 35 g of sugar was added depending on the treatment [Table 1]. The must was allowed to cool [36°C to 38°C] before adding 0.2% S. *cerevisiae* yeast inoculum [Tradi-Pan®] [previously activated in 50 mL of water and 5 g of sugar] and stirred to homogenize.

An airlock [CO_2 trap] with water was placed in each bioreactor and left to ferment for 48 h at room temperature [37°C] [Zavala et al., 2018].

The fermentation process was stopped by pasteurization in a water bath at a temperature of 75°C for 10 minutes to inactivate the yeasts. Each treatment was replicated three times.

Formulation of the fermented hot sauce [November 1, 2024]: in each resulting treatment [T1 and T2], the following were added: garlic [1%], salt [2%], vinegar [1%], chili [0.075%], oregano [0.075%], and xanthan gum [0.25%] as an emulsifier; finally, it was mixed with the help of a blender for 2 min [Ramírez-Sucre et al., 2016].

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The resulting sauce was stored at room temperature [32°C to 37°C] in sterile glass jars in portions of 50 g each.

Box 2

Table 1

Formulation of fermentable must based on costeño chili peppers *C. annuum* L..

Treat.	Chili [%]	Sugar [%]	H_2O [%]	Yeast [%]
T1	10.41	6.25	83.30	0.2
T2	10.41	8.33	83.30	0.2

Source: Own elaboration.

Shelf life

To estimate the shelf life of the hot sauce resulting from each treatment, it was left in storage [six months]. The pH and microbiological quality [aerobic mesophiles, total coliforms, and molds and yeasts] were evaluated in the first month of storage [December 2024], and the second analysis was performed after six months [June 2025].

A CONDUCTRONIC PH120 electrical potentiometer® was used to record the pH reading. Before taking the readings, it was calibrated with pH 4 and 7 buffer solutions, method 11.043/84.964.08/90 [AOAC, 1990].

In the microbiological quality assessment, the aerobic mesophiles technique [NOM-092-SSA- 1994], total coliforms [NOM-112-SSA1-1994], and molds and yeasts [NOM-111-SSA1-1994] were used to determine safety.

The samples were handled in accordance with the recommendations of NOM-109-SSA1-1994. Five grams of sample were weighed under aseptic conditions, added to 45 mL of peptone water [ratio 1:9] and homogenized for 30 seconds with the aid of a vortex; this was the first dilution [10^{-1}].

One mL of the suspension was taken and placed in a tube containing 9 mL of peptone water, and so on up to 10 [$^{-5}$] [NOM-110-SSA1-1994].

The results obtained were statistically analyzed by mean, standard deviation, and one-way analysis of variance where appropriate.

Results

Figure 2 shows costeño chili plants with green fruit [a], medium-ripe fruit [b], and ripe fruit [c]; when ripe, producers harvest, dehydrate, and market them.

Degree of ripeness

Table 2 shows the different degrees of ripeness of the costeño chili peppers estimated visually.

The description begins with the 100% green chili [M0], the degrees of ripeness were M1: 20% green and 80% purple, M2: 5% green and 95% yellow, M3: 25% yellow and 75% orange,

Box 3

Table 2

Degree of maturity of the costeño chili peppers *C. annuum* L.

Degree of ripeness	Color [Code]	Color estimate [%]
M0	Green [#57B12F]	100% green
M1	Purple [#E56E00]	20% green and 80% purple
M2	Yellow [#E56E00]	5% green and 95% yellow
M3	Orange [#E2550A]	25% yellow and 75% orange
M4	Light red [#CA0B0B]	15% orange and 85% cherry red
M5	Cherry red [#AC0505]	100% cherry red
M6	Carmine red [#8A0808]	100% carmine red

Source: Own elaboration.

The six degrees of ripeness of the costeño chili peppers *C. annuum* L [M1 to M6] observed and coded [Color-hex palette, 2010-2024] are shown in Figure 3.

Box 4

Figure 3

Degrees of maturity of the costeño chili peppers *C. annuum*: M1 to M6.

Source: Own elaboration.

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Proximal analysis of the fruit

Analysis of the proximal composition of the fruit of the costeño chili peppers *C. annuum* L. at optimal maturity [M5 and M6] [Table 3] revealed the following results.

Box 5

Table 3

Proximal composition of the costeño chili peppers *C. annuum* L.

Parameter	Content [%]
Moisture	79.41 ± 0.29
Total ash	1.52 ± 0.06
Total fat	1.44 ± 0.42
Crude fiber	7.96 ± 0.15
Total protein	5.89 ± 0.40
*NFE	3.78

**NFE: Nitrogen-Free Extract.*
Source: Own elaboration.

The costeño chili peppers fruit had a moisture content of 79.41 ± 0.29%, total ash content of 1.52% ± 0.06, total fat content of 1.44% ± 0.42, 7.96% ± 0.15 crude fiber, 5.89% ± 0.40 proximate protein, and 3.78% soluble carbohydrates [NFE].

Shelf life of the sauce

The hot sauces made from costeño chili peppers resulting from treatments T1 and T2 fermented for 48 hours with *S. cerevisiae* yeast. They were then formulated with salt, vinegar, spices, and xanthan gum [Figura 4].

Box 6

Figure 4

Fermented hot sauce based of costeño chili peppers *C. annuum*, Treatments: T1 and T2 in duplicate [a and b].

Source: Own elaboration.

Table 4 shows that treatments T1 and T2 had an initial pH of 4.5 ± 0.0 and 4.45 ± 0.07, respectively, with slight reductions to 4.4 ± 0.0 and 4.36 ± 0.2 at six months, representing minimal variation and evidence of stable fermentation equilibrium.

Box 7

Table 4

Shelf life evaluation of costeño chili peppers hot sauce: pH.

Treatment	pH Month 1	Month 6
T1	4.5± 0	4.4± 0
T2	4.45± 0.07	4.36± 0.2

Source: Own elaboration.

In the microbiological analysis, no growth of aerobic mesophiles, total coliforms, molds, or yeasts was detected in any of the treatments or sampling points [one month and six months].

Discussion

Degree of ripeness.

It has been reported that the sweet chili peppers *C. annuum* L, grown in the Yucatan Peninsula, has six stages of fruit ripeness: G0 [light green], G1 [dark green], G2 [green with red portion], G3 [green with red], G4 [red], and G5 [deep red] [Santamaría et al., 2022].

Paredes et al. [2019] reported five degrees of maturity in the bell chili peppers *C. annuum*: M1 [100% green], M2 [10% to 30% mature], M3 [40% to 60% mature], M4 [70% to 90% ripe], and M5 [100% ripe], detected using hyperspectral images in the visible range [380 to 750 nm] and digital images [RGB] converted to CIELAB color space.

Proximal analysis of the fruit.

The moisture content detected in the costeño chili peppers fruit indicated a high water content characteristic of fresh fruits at optimal maturity, possibly related to the climatic conditions [tropical-humid] of the state of Tabasco. This value is slightly lower than that reported by Solís-Marroquín et al. [2017] for the "siete caldos" chili [81.43%].

The total ash content recorded in the analyzed fruit [1.52% ± 0.06] is considerably lower than that reported for the "siete caldos" chili peppers [6.0% ± 0.006].

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The difference in mineral composition or total ash content in *C. annuum* chilies could be related to varietal genetic factors, soil conditions, and agronomic management practices [Álvarez-Ríos et al., 2019; De la Cruz-Lázaro et al., 2020]. Several studies have shown that both variety type and soil fertility significantly influence the absorption and accumulation of essential minerals in chili [Rico-García et al., 2018].

The observed proximal fat content [1.44% ± 0.42] in costeño chili peppers is lower than that reported in "siete caldos" chili peppers [8.0 ± 0.006%]. The low lipid content is characteristic of most fresh chili peppers varieties and reflects the nature of the fruit as a source of carbohydrates, fiber, and bioactive compounds.

As mentioned above, fresh chilies such as x'catik, dulce, and their F1 hybrid have a nutritional composition rich in carbohydrates, crude fiber, protein, and bioactive compounds [capsaicin, flavonoids, and total phenols], but low in fat [Mis-Valdez et al., 2022].

The crude fiber content [7.96% ± 0.15] of the costeño chili peppers is lower than that of the "siete caldos" chili [12.0 ± 0.006%]; however, it represents a considerable source of dietary fiber.

Fiber contributes significantly to digestive health and the regulation of glucose and blood cholesterol levels [Mis-Valdez et al., 2022]. Studies have shown that regular consumption of fiber-rich vegetables, such as chili peppers, can promote healthy gut microbiota and reduce the risk of metabolic diseases [Pihelgas et al., 2025].

The protein content in different varieties of chili peppers *C. annuum* can vary considerably due to genetic, environmental, and post-harvest handling factors. In this context, the costeño chili peppers had a low protein content [5.89% ± 0.40] compared to the high value of the "siete caldos" chili peppers [16.69% ± 0.006%]. This difference could indicate a possible influence of genotype on protein accumulation in fruit tissues.

Protein in plant products such as chili peppers is nutritionally and technologically important, as it can influence properties such as texture, stability, and functionality of the food [Romero-Luna et al., 2022].

The ELN related to soluble carbohydrates [3.78%] and the fiber content of the costeño chili peppers fruit indicate that total carbohydrates comprise approximately 11.74% of the fresh weight of the fruit. The results obtained reveal the nutritional profile of the costeño chili, which significantly differentiates it from other varieties of *C. annuum* such as the "siete caldos" chili peppers. The variations observed, particularly in fiber content [7.96%], protein [5.89% vs. 16.69%], ash [1.52% vs. 6.0%], and fat [1.44% vs. 8.0%], suggest considerable genetic variability within the species [Aguilar-Rincón et al., 2010].

The proximal profile of the costeño chili is consistent with the ranges reported for Mexican varieties of *C. annuum*. Other chili peppers have shown variable ash [8.18%] and protein [8.90%] contents, confirming that there is considerable diversity in nutritional composition within the species, influenced by genetic, environmental, and agronomic management factors.

The results of the proximate analysis provide fundamental information for the development of food products based on costeño chili peppers. The moderate fiber and protein content, together with the low lipid content, suggests potential for dehydrated products, sauces, condiments, and other derivatives that maintain nutritional value while extending shelf life.

Shelf life of the sauce

Fermented hot sauces based of costeño chili peppers resulting from treatments T1 [6.25% sugar] and T2 [8.33% sugar] in duplicate, fermented for 48 hours with yeast. Subsequently, formulated with salt, vinegar, spices [oregano and pepper], and xanthan gum.

The ability of xanthan gum to keep particles in suspension was crucial in hot sauces containing fragments of chili, spices, or plant materials. Its action as a suspending agent prevents sedimentation during storage, ensuring product homogeneity and a consistent sensory experience for the consumer [Yaseen et al., 2005]. The stabilizing effect of xanthan gum is better than that of other gums. It has strong thermal stability. Normal low-temperature disinfection does not affect it, making it ideal for pasteurization processes commonly used in the hot sauce industry [Ramírez-Sucre et al., 2016].

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The compatibility of xanthan gum with capsaicinoids, the compounds responsible for the heat in chili, is an important factor for its application in hot sauces. Studies have shown that xanthan gum does not interfere with the sensory perception of spiciness and may even contribute to a more controlled release of capsaicinoids, modulating the intensity and duration of the spicy sensation [Prescott et al., 1993].

In systems containing ethanol, such as alcoholically fermented sauces, xanthan gum maintains its stabilizing functionality, although an adjustment in concentrations may be required due to the lower polarity of the medium [Tabassum et al., 2025]. The presence of alcohol may slightly reduce the effectiveness of xanthan gum as a thickener, but does not significantly compromise its emulsifying properties.

The initial concentration of fermentable sugars [°Brix] determines the alcoholic potential of the final product, so it was optimized to maximize fermentation efficiency without creating conditions of excessive osmotic stress for the yeast. Sugar concentrations between 15-25 °Brix have been shown to be adequate for most vegetable fermentation applications [Jackson, 2008].

The must from costeño chili peppers has a unique chemical composition characterized by the presence of capsaicinoids, phenolic compounds, carotenoids, and other secondary metabolites that can interact with the fermentation process [Topuz & Ozdemir, 2007].

However, in the present study, these compounds did not affect the fermentation efficiency and metabolism of S. *cerevisiae* yeast, as the fermentation of the costeño chili must was successful.

The pH values recorded in treatments T1 and T2 of the fermented hot sauces demonstrated pH stability and microbiological safety based of chili peppers *C. annuum* L., during six months of storage. These values were within the optimal range of 3.5 to 6.0 recommended for yeast development and the inhibition of pathogenic microorganisms [Fleet & Heard, 1993].

They exceeded the acidity levels reported in sauces formulated with alcoholic beverages, whose pH varies between 3.10 and 3.85 [Alemán et al., 2023]. Chung et al. [1988] pointed out that pH levels close to 4.0 favor the preservation of fermented foods.

The absence of aerobic mesophile growth in both treatments throughout the evaluation period indicates that the fermented sauce maintains conditions that effectively inhibit the development of general microbial flora. This result is essential to ensure the safety of the product during its shelf life.

The complete absence of total coliforms at both sampling points confirmed that the fermented sauce does not present a risk of enteric contamination and maintains the appropriate hygienic conditions for a food product intended for human consumption.

The absence of fungal growth during the six-month evaluation period demonstrated that the pH conditions and antimicrobial activity derived from alcoholic fermentation provided effective protection against fungal spoilage, a critical factor in products with relatively high moisture content.

These results reinforce the effectiveness of the natural preservation system based on alcoholic fermentation, which promotes the formation of ethanol, an antimicrobial compound that creates an environment unsuitable for spoilage and pathogenic microorganisms [Adams & Moss, 2008].

In addition, fermentation not only contributed to product safety, but may also promote the release of bioactive compounds, such as phenolic compounds and carotenoids, through enzymatic processes, which improves both their nutritional value and antioxidant properties [Dávalos et al., 2004; Moreno-Arribas & Polo, 2009].

This phenomenon has been described in other fermented plant products and represents an additional functional advantage.

The slight minimal differences observed between T1 and T2, especially the higher standard deviation in treatment T2 at six months [±0.2], could be attributed to variations in the fermentation process or storage conditions.

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However, these did not compromise the overall stability of the product, so both treatments are viable from a microbiological and physicochemical point of view.

The development of hot sauces fermented by alcoholic fermentation represents a technological innovation that combines ancestral culinary traditions with modern scientific knowledge. This approach offers opportunities for the valorization of local chili varieties, such as the Tabasco costeño chili peppers, generating products with added value and differentiated characteristics in the market [Steinkraus, 2006].

Finally, the observed behavior suggests that costeño chili peppers fermented sauce can maintain its safety, stability, and functional potential for at least six months without the need for chemical preservatives. This offers a significant commercial advantage, especially for costeño chili peppers producers in the community of El Bajío, Jonuta, Tabasco, who have a high level of food insecurity and are seeking natural and sustainable alternatives to preserve and add value to traditional products.

Conclusion

Six degrees of maturity [M1 to M6] were detected in the fruit of the costeño chili especially for costeño chili peppers producers in the community *C. annuum* L, which is a source of fiber and protein when optimally ripe.

The fermented hot sauce made from costeño chili peppers showed stability [pH and absence of microorganisms] during the evaluated shelf life [six months], confirming that this preservation method is an alternative for adding value to the production of costeño chili peppers grown in the rural community of El Bajío, R/a Boca de San Jerónimo, Jonuta, Tabasco.

The results suggest the need to evaluate longer periods to determine the actual shelf life limit of the product. In addition, it would be valuable to include sensory evaluations to determine whether the organoleptic characteristics remain at the same level as the microbiological and physicochemical stability.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest. They have no financial interests or relationships that may have influenced the article reported in this article.

Author contribution

González-De la Cruz, Sesilu Montserrat [SMGC]: She developed the research from which he will obtain the degree of Maestra en Seguridad Alimentaria, División Académica de Ciencias Agropecuarias. Universidad.

Velázquez-Martínez, José Rodolfo: Human Resource Training [SMGC] and research management.

González-de la Cruz, José Ulises: Technical manager of the social responsibility project that led to this research. He collected samples and visited costeño chili producers.

De la Cruz-Leyva, María Concepción: Support in the development of the experiment, preparation and evaluation of the fermented hot sauce.

Availability of data and materials

The data obtained are available upon request.

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Article

Current techniques for evaluating peach quality: Analysis and synthesis of the state of the art

Técnicas actuales para evaluar la calidad del melocotón: análisis y síntesis del estado actual de la técnica

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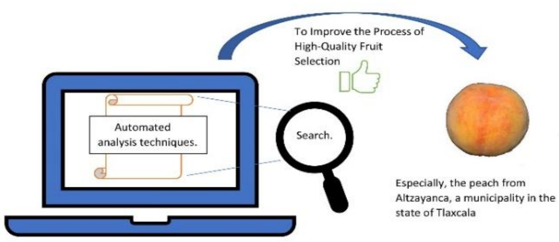
Abstract

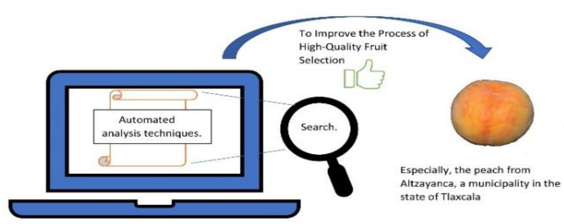
In this work, we present a comprehensive review of the most recent research on the automation of fruit selection and sorting processes. In this compilation, we analyzed 50 recent peer-reviewed research articles that demonstrate the application of advanced techniques such as CV [Computer Vision], CNN [Convolutional Neural Network], DIP [Digital Image Processing], and SVM [Support Vector Machine], achieving recognition accuracies above 95% in several cases. Likewise, the in-depth analysis of 10 studies focused specifically on peaches reveals that CNN- and SVM-based models [using RGB and near-infrared images] are particularly effective at identifying the highest quality peaches. This information guides us in the implementation of computer vision and machine learning techniques to automate the evaluation of peach quality in Altzayanca, Tlaxcala, Mexico, with the aim of improving harvesting efficiency and reducing operational costs. Mexico stands out in this sector by contributing the largest number of published research studies on peach quality.



Computer vision, Fruit quality, Peach

Resumen

En este trabajo, presentamos una revisión exhaustiva de las investigaciones más recientes sobre la automatización de los procesos de selección y clasificación de frutas. En esta recopilación, hemos analizado 50 artículos de investigación recientes revisados por pares que demuestran la aplicación de técnicas avanzadas como CV [visión artificial], CNN [red neuronal convolucional], DIP [procesamiento digital de imágenes] y SVM [máquina de vectores de soporte], logrando precisiones de reconocimiento superiores al 95 % en varios casos. Asimismo, el análisis en profundidad de 10 estudios centrados específicamente en los melocotones revela que los modelos basados en CNN y SVM [que utilizan imágenes RGB y de infrarrojo cercano] son particularmente eficaces para identificar los melocotones de mayor calidad. Esta información nos guía en la implementación de técnicas de visión artificial y aprendizaje automático para automatizar la evaluación de la calidad de los melocotones en Altzayanca, Tlaxcala, México, con el objetivo de mejorar la eficiencia de la cosecha y reducir los costos operativos. México destaca en este sector por aportar el mayor número de estudios de investigación publicados sobre la calidad de los melocotones.



Visión artificial, Calidad de la fruta, Melocotón

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

The modernization of agriculture has made it essential to develop **automatic methods** to accurately **and efficiently** assess crop quality. Various studies indicate that barriers such as lack of credit and insufficient information on the optimal use of new tools are common factors that slow down technological adoption in agriculture [QFD, 2020].

In this context, the review of the state of the art shows us different techniques used for the automation of the process of selecting quality fruits, it is an important activity for the guidance and decision-making on the techniques to be used. This analysis will help us integrate accessible computer vision and machine learning tools, so that local farmers can implement them. In this research, applications that use a single technique are observed, and others that present a combination of them and different methods to expand the range of variables in order to obtain more precise results regarding the selection of fruits, optimizing this part of the process.

This information obtained from reliable databases such as ScienceDirect, IEEE, among others, supports decision-making for future work related to the automatic analysis of the fruit selection process.

The sections of the article are briefly described. Section **2: Bibliographic analysis.** Section 3: **Proposed methodology:** details the methodology proposed in this paper for the correct search for the necessary information for the future implementation of an automatic analysis of fruits, especially peaches, and the stages of development. Subsequently, in **section 4:** the results and findings obtained are presented. Section 5: opens the discussion topic. Finally, **section 6** presents the general conclusions of the research and possible future lines of work.

Bibliographic analysis [50 articles]

A compilation of 50 recent scientific articles is presented, considering experimental studies and literature review, this information is essential to support and guide a research proposal on the automatic identification of peach quality in a specific locality of the country.

The analysis of the information from the scientific articles was carried out, graphing important data such as the year in which this type of article has been published the most, which countries implement these automatic systems, the precision of the techniques used, among others.

Below is the graphic study of the aforementioned scientific articles.

In Figure 1, we can see a comparative analysis of the various recently published researches, the graph shows the number of articles and their corresponding years, we can identify that the year 2023 and the year 2024 have been the most relevant years in research in the automatic analysis of fruit quality. This gives us an indication that this type of research is still being carried out recently.

Box 1

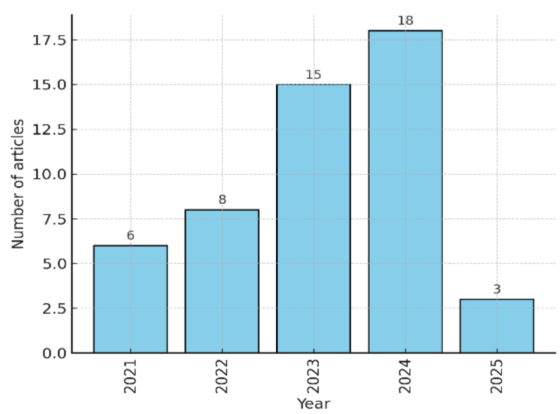

Figure 1
Comparison of the articles reviewed from 2021 to 2025
Source: own creation.

Figure 2 shows the percentage of articles that only review the existing literature and the other percentage are articles that apply the techniques they propose [review and experimental].

We can see that 24% of the 50 articles taken for this state of the art are literature reviews [articles that focus on literature] and 76% are experimental articles. [articles that apply the methodology used].

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Box 2

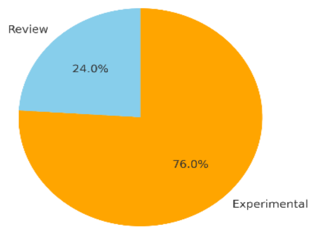

Figure 2

Percentage of literature review articles and experimental articles

Figure 3 presents the analysis of the research of the 50 articles analyzed by country or region. We can observe that research carried out in countries such as the United States, China, Mexico and India predominates, followed by studies in Europe and, to a lesser extent, in Latin America.

Box 3

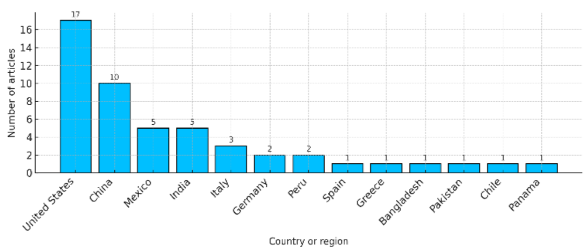

Figure 1

Article publications by country or region.

In Figure 4, we observe the predominant techniques and the least used techniques in automatic analysis to evaluate the quality of fruits. The most used techniques were identified: CV, CNN, DIP, this information allows us to identify areas of opportunity by innovating methodologies and techniques that are almost not used, or to be guided by the most used techniques and employ improvements in these techniques.

Box 4

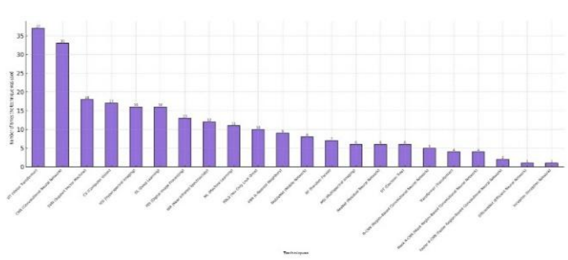

Figure *4*

Techniques used for the automatic analysis of fruit quality

Figure 5 shows the percentage distribution of the 50 articles analyzed according to their level of accuracy achieved or estimated. It is observed that **68.0% of the studies** have a **very high accuracy [≥ 95%]**, while **18.0%** reach a **high precision [90%–94.9%]. 14.0% of the articles** are in the **medium accuracy** category, corresponding to approximate estimates close to < 90%, generally from literature review articles or those that do not report exact metrics. With this graph we can see that most of the articles present acceptable accuracy of effectiveness.

Box 5

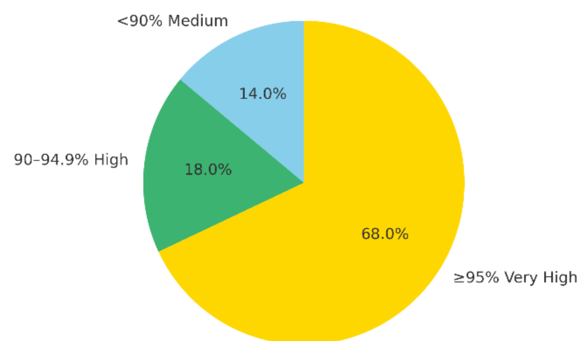

Figure 2.

Percentage of effectiveness of the 50 articles analyzed.

In Table 1, we can see the main areas of opportunity of the research detected from this analysis. The techniques used, the places where this type of research has been carried out, the effectiveness of the techniques, are important indicators to analyze in the table.

2.1 Review of the literature on automatic techniques for fruit selection in agriculture

Next, a documentary analysis of 10 articles of different methodologies applied to automatic analysis is presented, the selection was made after reading the articles and seeing that the methodologies they talk about are interesting since they optimize the process of fruit selection, in some cases they combine techniques to reach a better result, The accuracies they talk about are acceptable and in some high-precision studies, from these articles we can identify areas of opportunity for future implementations of automatic techniques for fruit selection.

Box 6

Table 1

Traffic light of areas of opportunity detected in the analysis of the state of the art.

Analyzed Area	Current Situation	Traffic Light Interpretation	Status	Opportunity
Computer vision techniques and advanced models (CNN, vision transformer, multispectral vision, 3D vision, deep learning).	Some areas are still missing (not all studies presented them).	● (yellow)	In development	Learning more about these advanced vision techniques and learning models, and applying one of them if possible.
Research in Mexico and Latin America.	There is greater presence in Mexico and little in Latin America.	● (yellow)	In development	Improve the techniques already applied in Mexico and, if they are functional, expand them to future works.
Experimental articles.	90% of the articles use experimental techniques.	● (green)	High coverage	Since most of the articles are experimental, they could be applied to future works or combined to achieve better results depending on the required needs.

Source: own creation.

2.1.1 Real-time visual inspection system for fruit sorting using computer vision and deep learning techniques

This study proposed an automated visual inspection system to classify the freshness and appearance of fruits, using computer vision and deep learning techniques. They trained and tested several models, such as ResNet [*Residual Network],* DenseNet [*Densely Connected Convolutional Network*], MobileNetV2 [Mobile Network Version 2], NASNet [*Neural Architecture Search Network*], and EfficientNet [*Efficient Convolutional Network*] to determine the best model for fruit grading. The system, based on a low-cost Raspberry Pi module, segments and sorts fruits in real time. [Ismail & Malik, 2022]

2.1.2 In-situ analysis of fruits using 3D LiDAR point clouds of the normalized difference vegetation index [NDVI].

In this work they developed a non-invasive method using LiDAR [*Light Detection and Ranging*] to analyze fruit development on trees and improve agricultural production management.

Their objective was to measure the number of fruits, their size, and the amount of chlorophyll, which is related to the ripeness of the skin of the fruits. During apple development [between 65 and 130 days after flowering], LiDAR laser scanners were used to generate 3D point clouds that allowed the calculation of the *Normalized Difference Vegetation Index- Light Detection and Ranging,* which correlated with the chlorophyll content of the fruits. [Tsoulias et al., 2023]

2.1.3 Segmentation of fruit tree images comparing the Mask R-CNN and Vision Transformer models. Application in a novel algorithm for pixel-based fruit size estimation.

In this study, they trained a *deep learning model*, Mask R-CNN [*Mask Region-Based Convolutional Neural Network*], to segment pomegranate fruits on the tree, and compared its performance with other models based on VIT [*Vision Transformer*], Grounding DINO [*DETR with Improved denoising anchor boxes*] and Segment Anything Model.

The results showed that Mask R-CNN performed better in terms of F1 score and AP [Average Precision] accuracy metrics as well as a lower computational cost, compared to the other models. [Giménez-Gallego et al., 2024]

2.1.4 Classification of the ripeness status of papaya fruits based on machine learning and transfer learning approaches.

This study proposed non-destructive methods based on machine learning and transfer learning to classify the ripeness status of papaya fruits. 300 images of papayas at three stages of maturity were used, comparing machine learning approaches and pre-trained models.

The KNN [***K-Nearest Neighbors*****] model** with HOG [*Histogram of Oriented Gradients*] achieved 100% accuracy in machine learning, while, in transfer learning, the VGG19 [*Visual Geometry Group 19*] model also achieved 100% accuracy, surpassing previous methods by 6% accuracy [Behera et al., 2021]

2.1.5 A CNN-LSTM-based vision system for robotic sorting of citrus fruits.

In this study, they presented an automated sorting system for citrus fruits based on CNN and LSTM [*Long Short-Term Memory*], designed to work with robotic grippers in real time. The system uses CNN to detect defective oranges and classify them, while LSTM predicts the future position of fruits based on sequential image data. Merging these nets makes it possible to track oranges during their rotation, identify their types, and predict their trajectory for precise robotic control. [Yu et al., 2024]

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2.1.6 Computer Vision in Smart Agriculture and Precision Agriculture: Techniques and Applications.

In this paper they explored the integration of intelligent systems based on computer vision and artificial intelligence in agriculture, which is transforming traditional agricultural practices.

Digitalization and automation promise to increase productivity, improve sustainability, and address global challenges such as food safety. The article provides a comprehensive view of how vision technologies are applied at various stages of the digital crop lifecycle within precision agriculture. Imaging techniques used in image acquisition, analysis, and processing are discussed, and key metrics for evaluating crops are examined. [Ghazal et al., 2024]

2.1.7 Artificial vision system for real-time detection of debris in mechanical harvesters of wild blueberries.

In this study, they developed a debris detection system [leaves and stems] during the mechanical harvesting of wild blueberries to improve fruit quality.

Two Logitech C920 cameras mounted on a combine were used to capture images of two commercial fields in Nova Scotia, generating a dataset of 1000 images. Two convolutional neural networks [CNNs], YOLOv3 and YOLOv3-SPP [***You Only Look Once version 3 with Spatial Pyramid Pooling***] were trained and compared using different image magnifications [sharpness, brightness, contrast, etc.]. [Das et al., 2023]

2.1.8 Robotic prototype fruit picking and sorting system based on computer vision.

In this study, they presented a prototype of an all-in-one robotic system for sorting and harvesting fruits, which uses computer vision to improve efficiency and reduce losses in harvesting and sorting. The system detects the fruits using machine vision algorithms including color conversion, skin segmentation, and defect detection, implemented in Python using OpenCV [*Open Source Computer Vision Library*] The detection data is sent to a 4-DOF [*Degree of Freedom] robotic arm*, which picks and places the fruits with the help of servo motors. [Dairath et al., 2023]

2.1.9 A New Computer Vision Workflow to Evaluate Performance Quality Attributes in Bush Bean [Phaseolus vulgaris L.]

In this study, they presented a new computer vision workflow to assess the quality of bush bean [*Phaseolus vulgaris*] pods, with the aim of replacing manual evaluations performed by experts. Images of 40 bean varieties were used to develop and validate the system, which analyzes traits such as pod shape, color, length, caliber, curvature, and luster. [Jollet et al., 2023]

2.1.10 A deep CNN approach to detecting and classifying local fruits through a web interface.

In this study, they presented an automated system based on deep learning for the identification and classification of fruits, designed to help consumers determine the type and quality of fruits in supermarkets. Given the complexity of the process due to factors such as low contrast and ambiguous fruit characteristics, the system uses deep neural networks such as ResNet-50, VGG-19 [*Visual Geometry Group 19-layer*], Inception-V3 [***Inception version 3*]**, and MobileNet [*Mobile Network*] to extract features from the images. [Rahman et al., 2023]

From this analysis, it was identified that most of the studies in the field of automatic fruit quality assessment apply conventional machine learning techniques, highlighting the use of CNN, SVM and RGB cameras. However, areas with opportunities for development persist, such as the incorporation of more advanced models, for example, **GNNs** [*Graph Neural Networks*], used in Asia and Europe for plant structure analysis and yield prediction [Chen et al., 2023; Bhagat et al., 2023], or **VITs**, applied in China, the United States, and Europe for crop classification and segmentation [Chen et al., 2025; Dosovitskiy et al., 2021].

In contrast, in Latin America, and particularly in Mexico, its implementation remains scarce. This opens up a valuable line of research that can strengthen local agricultural competitiveness by adopting these cutting-edge techniques. This overview highlights the need to explore more innovative and contextualized approaches that integrate computer vision, emerging sensors, and deep learning models, aligned to the specific needs of agricultural products such as peaches.

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2.2 Documentary analysis of automated techniques applied to peaches

Now, we will talk about a documentary analysis of 10 articles that talk about different automatic analysis techniques for decision-making in the area of agriculture, taking the peach as a specific fruit, the samples obtained in the following studies generally come from China, Mexico and India, this analysis allows us to identify relevant areas of opportunity to strengthen this research and guide the analysis of new research.

2.2.1 Evaluation of machine learning models to identify peach varieties by leaf color.

This study employs machine learning models, mainly SVM, applied to color combinations in RGB and HSV spaces to classify peach varieties from leaf images. It was observed that the model obtained its best performance in the HSV space, achieving an accuracy of 84.1%, which demonstrates its usefulness for this type of analysis. [Ayala-Niño & González-Camacho, 2022]..

2.2.2 Classification of peach quality and ripeness using neural networks.

Digital processing techniques were combined with neural networks to classify peaches at different quality levels. The model achieved an accuracy of 94.58%, showing a high performance in the visual recognition of the fruit for commercial classification. [Luo et al., 2024].

2.2.3 Prediction of Peach Firmness with Computer Vision and Neural Networks

This paper integrates computer vision and backpropagation neural networks along with dielectric property analysis to predict peach firmness. The methodology reached an accuracy of 86.9%, highlighting its potential for non-destructive evaluations in post-harvest. [Zhang et al., 2020].

2.2.4 Classification of peach fruits into ripe, immature and damaged.

The study implements a convolutional neural network to classify peach fruits into three categories: ripe, immature, and damaged. The highest accuracy was 95.31% when differentiating between ripe and immature, which validates its applicability for automated harvesting. [Arévalo Zenteno et al., 2021].

2.2.5 Application of non-destructive techniques for peach quality inspection [review].

This review examines non-destructive techniques such as NIR spectroscopy, hyperspectral imaging, computer vision, and dielectric sensors, used to assess the ripeness, firmness, and internal quality of the peach. It provides a comprehensive framework of current technologies and their applicability. [Qi et al., 2024].

2.2.6 Machine learning algorithms to identify peach varieties [with leaves].

Through RGB images of leaves, this work applied SVM to classify peach varieties. The model achieved a remarkable accuracy of 98.7%, consolidating itself as an effective tool for varietal identification in early stages. [Ayala-Niño & González-Camacho, 2024].

2.2.7 Comprehensive evaluation of peach quality using PCA and neural networks.

The research combined PCA [Principal Component Analysis] and CNN analysis techniques to evaluate peach quality through physicochemical attributes and dielectric properties. The accuracy achieved was 86.9%, validating its effectiveness for automated classification. [Zhang et al., 2020].

2.2.8 Review of non-destructive techniques for fruit evaluation [in general].

This study reviews recent advances in non-destructive technologies applied to fruits, including computer vision, electronic nose, optical and acoustic spectroscopy. Although it does not focus only on peaches, it suggests a wide potential of these technologies in agricultural applications. [Ranjani et al., 2024].

2.2.9 Classification of peach varieties by leaf color [HSV - 84.1%].

This comparative analysis evaluated SVM, Random Forest, and Multilayer Perceptron to classify peach varieties using leaf imaging. SVM with HSV reached an accuracy of 84.1%, standing out among the models evaluated. [Ayala-Niño & González-Camacho, 2022].

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2.2.10 Non-destructive classification of the ripeness state of the peach by spectroscopy using visible/NIR spectroscopy and computer vision

This study ranked peach ripeness and predicted internal parameters such as soluble solids. The combination of techniques improved accuracy and applicability in post-harvest quality control. [Donis-González et al., 2020] In the documentary analysis carried out we can identify the remarkable progress in the application of automated techniques for the evaluation and classification of peaches. This technological panorama represents a solid basis to guide and enrich the development of this research, especially in future works such as the implementation of automatic models for decision-making in the selection of peaches. A graphic analysis of the aforementioned articles that talk about peaches is presented

In Figure 6, we can see that of the 10 articles analyzed, 90% of the studies on peach analysis are experimental, which indicates a strong focus on the direct application of techniques, while only 10% corresponds to a review analysis, it should be noted that it is also important since its information broadens our panorama of these techniques and methodologies existing today.

Box 7

Figure 6
Classification of articles on automatic analysis techniques and methodologies in peaches.

In Figure 7, we can see the different techniques used by the aforementioned articles and the accuracy of each of them evaluated from 0 to 100% accuracy. It is observed that several computational techniques for each research, such as SVM, CNN, DIP, and NIR, reach values above 95%, while the Most approaches are above 83%, indicating a good overall performance in the classification and evaluation of peaches.

Box 8

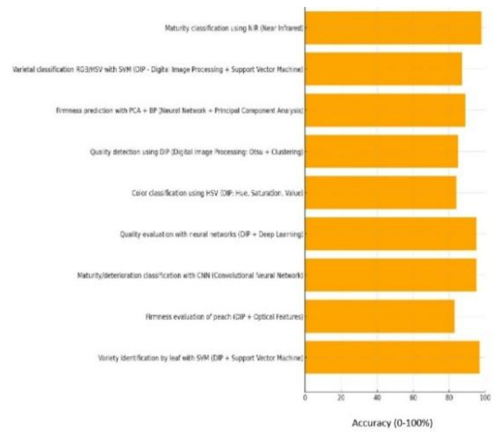

Figure 3
Techniques used by experimental articles that talk about peaches, and their precision achieved
Source: own creation.

Figure 8 shows the distribution of the main techniques used in the articles that address the automatic analysis of peach quality. It is observed that SVM-based methods are the most widely used, standing out for their effectiveness in classification tasks, especially when using leaf images or color characteristics.

It is followed by DIP techniques, widely applied in segmentation, firmness detection and classification of maturity states. It also identifies the use of and methods classified as "other", which generally include hybrid approaches or combinations of techniques. This distribution shows a preference for supervised learning methods that offer high precision and versatility to different types of visual or spectral inputs.

Box 9

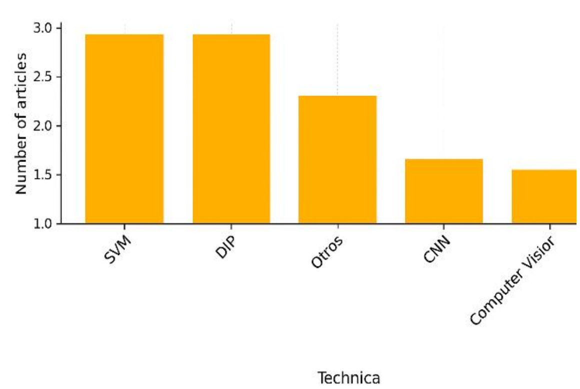

Figure 8
Most commonly used techniques for the recognition of peach quality.

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In Figure 9, we observe that of the 10 articles cited there are three countries that have the greatest incidence with the automatic analysis of peach quality, Mexico occupies the first position that uses these methodologies since of the 10 articles 5 are from this country, followed by China with 4 articles of the 10 articles cited and finally India with 1 article, it should be noted that in the search for articles about peaches, more articles from the country of Mexico were found. This shows a growing national interest in the use of non-destructive technologies applied to this fruit.

Box 10

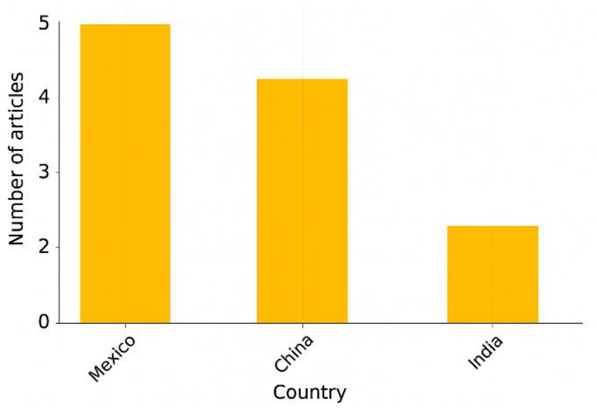

Figure 4.
Distribution of peach literature by country.
Source: own creation.

From the review of the 10 articles of the peach quality analysis, we can highlight that there are several automatic analysis techniques from which we can take concepts or ideas that are of help for implementation in future works. By observing the graphs of this analysis, especially the graph of the countries, we identified that Mexico is in the first position, by carrying out this research we contribute to that broad panorama of research of the peach analysis that is carried out in Mexico.

3. Proposed methodology

The methodology presented below describes the steps followed to search, select and analyze scientific literature related to the automatic analysis of peach quality. The main interest was to establish a systematic process that would allow the identification of relevant, recent and scientifically rigorous articles, so that the information collected would serve as a basis to answer the research question and guide the development of the study.

To this end, specific keywords and search strings were defined, inclusion and exclusion criteria were applied, and a progressive analysis was carried out that first covered a general overview and then focused on studies directly related to peaches

Step 1- Research Question

The research question helps us to delimit the focus of our studies, helping us to facilitate the search for articles in the different scientific databases of the web, together with the search criteria we can carry out an analysis more focused on what we are looking for.

What is the best automatic analysis system to evaluate the quality of peaches in the municipality of Altzayanca in the state of Tlaxcala in Mexico?

Step 2- Keywords and Search StringBoolean Operators and Bilingual Terms

It helps us translate our research question into technical terms by allowing us to find relevant articles on a scientific basis.

Boolean operators [AND, OR, NOT] allow you to combine or exclude terms, making it easier to search:

AND: To include all terms.
OR: To include any of the terms.
NOTE: To exclude terms. Application to topics of interest:
"peach" OR "prunus persica"
This ensures that studies are found on the peach, using both its common and scientific name.
"quality assessment" OR "quality evaluation" OR "fruit grading" OR "fruit classification" OR "postharvest quality"
It includes different ways of referring to the evaluation of the quality, classification or post-harvest state of the peach.
"automatic analysis" OR "computer vision" OR "image processing" OR "machine learning" OR "artificial intelligence" OR "deep learning" OR "non-destructive methods" OR "hyperspectral imaging" OR "NIR spectroscopy" OR "convolutional neural networks" OR "CNN" OR "support vector machine" OR "SVM"

These are the most widely used technologies to evaluate fruit quality automatically. For more results we do not include the country,

Huerta-Flores, Humberto, González-Meneses, Yesenia Noemí, Pedroza-Méndez, Blanca Estela and Ramírez-Cruz, José Federico. [2025]. Current techniques for evaluating peach quality: Analysis and synthesis of the state of the art. ECORFAN Journal-Ecuador. 12[22]1-14: e61222114.
https://doi.org/10.35429/EJE.2025.12.22.6.1.14

Step 3- Inclusion/Exclusion Criteria

Recent items, no more than 5 years old. Choose those that allow the work panorama to be clarified. Those where the term agriculture intervenes

Main: Research Articles, Review Articles, Data Articles.

Step 4- Analysis of 30 articlesExtraction of variables [year, country, technique, precision] and visual synthesis [Boxes 1–5].

Step 5- Focused review [peach]Selection of 10 articles and comparative analysis [Boxes 6–10].

Results

The models developed demonstrated high performance in automatic fruit sorting. The studies reviewed agree that the most widely used techniques for automated fruit inspection are those based on artificial vision and image processing. In particular, CNN-like deep learning models are widely used for fruit sorting and segmentation tasks.

For example, it is common to apply pre-trained architectures such as ResNet, VGG or TL [Transfer Learning] to differentiate fruit varieties or maturity levels. In addition, the analyses report that the key visual morphological features extracted are usually color, texture and shape of the fruit, using color segmentation and neural networks to detect diseases or defects. DIP with techniques such as filtering, segmentation for example, thresholding, edge detection and feature extraction is also a common stage prior to classification.

The reported accuracy levels vary depending on the complexity of the task and the type of method. Overall, most of the studies reviewed achieve high precisions: typically between 90% and 99% accuracy in quality or maturity classification. In fact, it has been observed that most research achieves accuracies in the range of ≥95%. However, only a minority of the cases report accuracies [<90%] in a sustained manner. It's interesting to see that a hybrid CNN + Transfer Learning system reported 100% accuracy in sorting ripe papayas using 300 tagged images.

Overall, the results indicate that current methodologies already produce acceptable levels of effectiveness, but they also pose the challenge of exceeding them for more demanding applications.

In the classification tasks, referring to the analysis of peach articles, an overall accuracy of close to 95% was obtained, with **precision and sensitivity values** greater than 90%. This translates into a high **F1-score [**evaluation metric for grading models] [≈0.92], indicating a good balance between the ability to correctly identify quality peaches and minimize false alarms.

The literature supports these performance levels: **Luo et al. [2024]** reported 94.58% accuracy when classifying peaches by quality level, while **Arévalo Zenteno et al. [2021]** reached 95.31% when differentiating ripe from unripe fruits in a similar way, in other fruit-growing contexts near-ideal metrics have been achieved for example, **Taner et al. [2024]** report accuracy of 99.78%, *recall* [also called sensitivity or true positive rate, measures **how well the model detects all real positive cases]** of 99.75% and F1 of 99.76% by classifying different apple varieties using a hybrid deep learning approach. These results highlight the potential efficacy of computer vision-based approaches when quality data and adequate model tuning are available.

In image **segmentation** tasks [pixel-by-pixel identification of peach regions], performance was also strong. The segmentation model achieved an **average Intersection over Union Index of** around 0.85 in a controlled environment, meaning that the predicted masks of peaches overlap by ~85% with actual areas, on average.

This strict metric confirms the system's ability to accurately delineate each fruit within the image. However, it was observed that the requirement for higher levels of overlap impacts the metric: for example, by raising the IoU threshold from 0.50 to 0.75, the average accuracy of the model can be reduced from ~84% to around ~65%, consistent with previous findings. Previous studies highlight the complexity of achieving near-exact matches in edge segmentation, especially in cases of partially hidden fruits or with fuzzy contours.

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This indicates that while the algorithm correctly identifies most peaches [high *recall*], achieving a near-perfect match in segmentation is more challenging. Even with this slight degradation under strict criteria, the F1 score at the mask level remained high [above 0.90], showing that the overall balance between well-segmented pixels and errors is still favorable.

Together, these metric results such as accuracy [measures the **proportion of positive predictions that were actually positive**], accuracy [measures the total percentage of correct predictions made by the model, considering both positive and negative], sensitivity [Recall], specificity [measures the model's ability to correctly identify negative cases] and F1 corroborate the effectiveness of the system to automate the classification of this fruit, achieving performances comparable to or superior to those obtained manually by human experts.

Comparison with Other Crops [Apple, Mango, Strawberry]

It is important to contrast the performance obtained in peaches with the results of similar techniques applied in other crops, in order to measure the generalization of the approach. In the case of **apples**, numerous studies have also achieved high success rates in computer vision tasks.

For example, in the detection of surface defects and quality classification of apples, accuracies greater than 90–95%, and even close to 99%, are reported in systems trained under controlled laboratory conditions. In classification of different varieties, approaches based on deep learning have achieved up to 99.7% accuracy in tests with organized, clean datasets and apply an improvement to them.

However, not all apple scenarios yield such high results: Luo et al. [2024] observed that their automatic method, originally designed for peaches, yielded only ~70% accuracy when applied to apples.

This difference suggests that the visual characteristics and intrinsic variability of each fruit [texture, color, shape] can significantly influence performance, sometimes requiring retraining or crop-specific adjustments.

In **mango**, the implementation of automatic techniques for quality selection and classification has also proven to be effective. A recent mango defect detection system using CNN networks achieved 98% accuracy in binary classification [healthy vs. defective fruits], demonstrating that deep learning techniques properly generalize to this complex-skinned fruit. Other work on mango reports performance in the range of 88–94% **accuracy** for maturity and quality classification, using combinations of traditional image processing and classical *machine learning* models. These values are comparable to those obtained in peaches, indicating that similar visual criteria [such as changes in color or presence of spots] can be captured by analogous algorithms trained on different fruits. In the case of **strawberries**, a smaller fruit with different characteristics, artificial vision techniques have also been applied for maturity classification and quality detection. The results in strawberry are usually slightly lower due to their high visual variability and lighting factors in the open field; Even so, close to 90% accuracy has been achieved in the classification of ripe vs. unripe strawberries. For example, Wang et al. [2024] implemented a hybrid system [YOLOv8+ model with image processing method] to detect and classify strawberries by degree of maturity, obtaining ~91.9% accuracy, with a false positive rate of only 5.03% and false negatives of 14.28%.

When comparing to apple, mango and strawberry, our focus on peaches shows competitive performance. The high accuracy and F1 scores obtained are consistent with those of other crops when similar techniques are used, although each species presents particular challenges. It should be noted that the best results are usually achieved when the system adapts to the particularities of the target fruit [either by calibrating parameters, extending training with specific images, or adjusting preprocessing], as reflected by the variations in performance between different studies available in the literature.

Validation in field conditions vs. simulated scenarios

To evaluate the **robustness** of some systems mentioned in the literature, tests were carried out both in controlled scenarios [simulating ideal lighting conditions and uniform background] and in real field conditions [outdoor gardens with changing natural lighting, complex bottoms and foliage obstruction].

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The results showed an expected variation in performance: in controlled laboratory environments, performance metrics were slightly higher, while in images captured in the open field a decrease in the accuracy and precision of the model was observed. These variations are consistent with reports by other authors that highlight the complexity of maintaining high yield in real scenarios: previous studies have noted that algorithms trained in controlled situations see their effectiveness degraded when applied in orchards with obstructions and environmental variability.

For example, [Giménez-Gallego et al. 2024] compared segmentation models in images of fruits on the tree [pomegranates] and found that while a mask generated by Mask R-CNN could achieve ~84% accuracy at low IoU thresholds, its pit performance reaches ~56% by demanding stricter matches. However, by employing newer VT-based architectures, the same study managed to retain 65.2% accuracy even with IoU = 0.75%, nearly doubling the capacity of conventional CNN models under complex conditions.

Discussion

The inclusion of more research articles would help to make the information presented even more complete. Regarding the information collected, the trends show high effectiveness with RGB images and supervised approaches [SVM/CNN]. Integrating sensors that can provide even more characteristics to the fruit quality process such as NIR, moisture sensors among others and recent architectures such as VT and GNNs can improve data robustness and thus greater acceptability of the final product. The inclusion of visualizations such as confounding matrices and ROC curves in future analyses is suggested, as they provide greater depth in the interpretation of the results and in the comparison with external standards [Arévalo Zenteno et al., 2021].

6. Conclusions and future work

There is significant advancement in the use of automated techniques to assess fruit quality, especially those based on computer vision and machine learning, the most effective techniques combine non-destructive approaches with robust algorithms such as CNN and SVM, achieving high levels of accuracy, A highlight is the consistency of the results.

While manual inspection tends to be subjective and variable, the algorithms applied generate uniform batch-by-batch sorting [Jangam et al., 2023].

Validation under field conditions showed that, even under variations in illumination and heterogeneity in the fruit surface, the model maintains a stable performance with an average F1-score of 0.92.

When compared with other crops such as apples or mangoes, the studies reviewed confirm a similar pattern: computer vision makes it possible to detect surface defects with high accuracy and optimize workflow in small and medium-scale agro-industries [Qi et al., 2024].

These findings support that the research carried out is of great help in understanding the advantages and disadvantages of certain techniques when it comes to applying them in future work. In addition, recent work by Cornejo Bendezu and Puscan Cáceres [2025] shows how the integration of DMAIC and Lean Manufacturing methodologies can strengthen process control in agribusiness, complementing the aforementioned technological advances. For his part, Bravo Espinoza [2025] has expanded the quality assessment strategies applied to fruits, highlighting the role of **computer vision** and **freeze-drying** processes.

In turn, Escobar Vera [2025] evidences the interdisciplinary expansion of digital analysis technologies, taking advantage of pigments and imaging techniques in sectors such as sustainability, which confirms the versatility of these tools.

The systematic review made it possible to identify that Mexico is very active in this field, so it is necessary to know these scientific contributions so that in localities such as Altzayanca these technologies can be implemented. There are areas of opportunity for innovation, especially incorporating more recent models such as VT or GNNs, which are not yet widely applied in this context.

The information collected lays the foundation for solid methodologies applicable in future work related to the automation of the selection of the peach quality analysis, which can directly benefit the producers of the municipality.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest. They have no known competing financial interests, nor personal relationships that could influence the item.

Authors' contribution

All authors contributed to the search for information and writing of the article.

Availability of data and materials

The data supporting the findings of this study come from research articles previously published in publicly accessible academic databases and institutional subscriptions [IEEE, ScienceDirect, Springer, Scielo, and Google Scholar].

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Abbreviations

CNN	Convolutional Neural Network
SVM	Support Vector Machine
DIP	Digital Image Processing
CV	Computer Vision
ResNet	Residual Network
DenseNet	Densely Connected Convolutional Network
MobileNetV2	Mobile Network Version 2
NASNet	Neural Architecture Search Network
EfficientNet	Efficient Convolutional Network
LiDAR	Light Detection and Ranging
NDVILiDAR	Normalized Difference Vegetation Index- Light Detection and Ranging
Mask R-CNN	Mask Region-Based Convolutional Neural Network]
VIT	Vision Transformer
DINO	DETR with Improved denoising anchor boxes
AP	Average Precision
KNN	K-Nearest Neighbors
HOG	Histogram of Oriented Gradients
KNN	K-Nearest Neighbors
HOG	Histogram of Oriented Gradients
VGG19	Visual Geometry Group 19
LSTM	Long Short-Term Memory
YOLOv3-SPP	You Only Look Once, version 3 with Spatial Pyramid Pooling
OpenCV	Open Source Computer Vision Library
4-DOF	Degree of Freedom
VGG-19	Visual Geometry Group 19-layer
Inception-V3	Inception version 3
MobileNet	Mobile Network
GNNs	Graph Neural Networks
TL	Transfer Learning

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Article

Cajititlán Lagoon: Conservation and utilization of endemic fish biodiversity, a sustainable source of energy

La laguna de Cajititlán, conservación y aprovechamiento de la biodiversidad de peces endémicos una fuente sostenible de energía.

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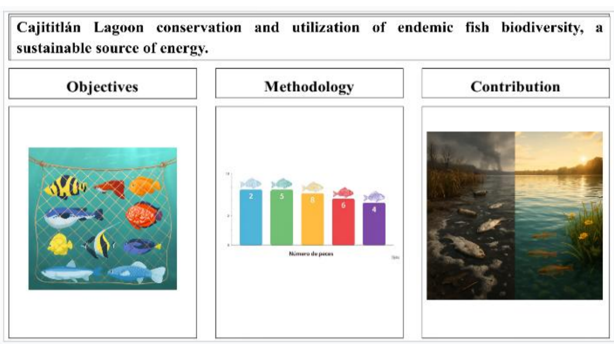
Abstract

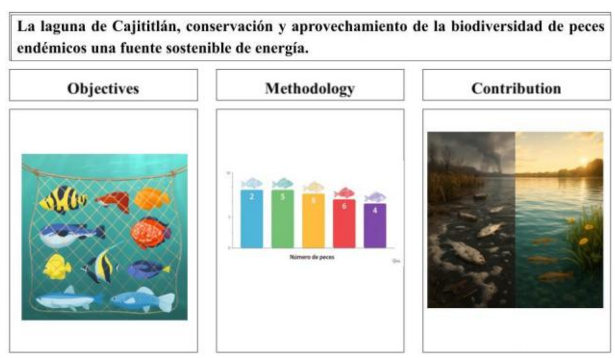
Bodies of water often aid in biodegradation processes, and when they are eutrophic, they have great potential to convert light energy into chemical energy through photosynthesis, producing biomass that gives rise to food chains. However, if the last link in the chain—fish—is not utilized, they accumulate in the body of water, and the overaccumulation of organic and living matter causes bioaccumulation, leading to the dominance of the strongest species and a loss of biodiversity. The present work aims to know the endemic species of fish that die recurrently in the lagoon of Cajititlán for this a limnological diagnosis of the lagoon was carried out, endemic species of fish were recovered and classified based on their morphology to study their identity as well as their environmental importance and it was found that the species that die correspond to endemic species in danger of extinction known as Charales [*Chirostoma jordani woolman*], tiritos [*Goodea atripinnis*], and classified as Threatened the popochas [*Algansea popoche*]. The work describes the importance of monitoring populations and establishing a sustainable use of them for the production of products for the food industry or biofuels otherwise overaccumulation will direct the ecosystem with irreversible consequences.



Biodiversity, Algansea popoche, Laguna.

Resumen

En los lagos se conducen procesos de biodegradación y reutilización de materia orgánica. Si el lago es eutrófico, las cadenas tróficas son muy activas estimuladas por la fotosíntesis. Si los peces no son aprovechados, se acumulan provocando un exceso de materia orgánica y organismos vivos que compiten por un mismo espacio. El objetivo del presente trabajo, fue identificar las especies de peces que mueren de forma recurrente en la laguna de Cajititlán. Se realizó un diagnóstico limnológico, se recuperaron ejemplares y se clasificaron con base en su morfología. Los resultados evidenciaron que las especies afectadas corresponden a endémicas en peligro de extinción, Charales [*Chirostoma jordani*] y tiritos [*Goodea atripinnis*] así como especies amenazadas: popochas [*Algansea popoche*]. Este estudio destaca la importancia de monitorear poblaciones y establecer estrategias de aprovechamiento sostenible. La sobreacumulación de biomasa conduce al deterioro del ecosistema con consecuencias irreversibles como la pérdida de biodiversidad.



Biodiversidad, Algansea Popoche, Laguna

Area: Advocacy and attention to national problems

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Introduction

The Cajititlán Lagoon is located in the state of Jalisco, in the middle portion of the central region between the coordinates 20° 28° north latitude and 103 ° 27° west longitude. Its length is estimated at 7.5 km with a width of 2 km and an average depth of 2.5 m, its water storage capacity is approximately 54 million m³. Due to its extent it is considered the second largest lake in the State of Jalisco preceded by Lake Chapala [Caro et al., 2017]. It is located on the skirts of the second highest mountain in the state, Cerro Viejo Chupinaya los Sabinos [declared protected natural area], surrounded by 5 localities: It currently faces eutrophication issues due to the discharge of untreated wastewater and stormwater runoff containing agrochemicals derived from agricultural activities [Perez-Rojas, 2019].

In 2005, Tlajomulco was the third highest growing metropolitan municipality in Mexico [10.8%], from 2010 to 2020 the population of Tlajomulco almost doubled and increased from 416,626 to patterns of land use change. According to the Comisión Estatal de los Derechos Humanos del Estado de Jalisco [ECHR] reported that particularly during 2021, 97% of the proceedings initiated relate to complaints about water wastage and 3% to the poor quality of water, [Casas & Great, 2025].

An agricultural ecosystem is composed of social, biotic and abiotic factors, which are independent and interrelated with energy flow, nutrient recycling and biodiversity. But their uncontrolled exploitation leads to habitat loss and fragmentation, introduction of exotic species, use of pesticides and reduction in the diversity of food resources. It significantly affects the diversity, distribution and functioning of ecosystems. [Monroy, 2025].

Box 1

Figure 1

Lagoon of Cajititlán, Jalisco Mexico.

Source [Ponce A., 2025]

Wetlands are transitional zones between terrestrial and aquatic, shallow ecosystems. And they create the conditions for the development of moisture-adapted species. Lakes and lagoons, are low-movement systems fed by streams, rivers, groundwater mantles, precipitation and surface runoff, it is worth mentioning that those located close to a population usually also feed from the discharge of treated wastewater. [modified from https://www.biodiversidad.gob.mx/ecosistemas/ecosismex/rios-y-lagos].

Wetlands are inhabited by aquatic plants, fish, amphibians, reptiles, insects, molluscs and crustaceans mainly. Humanity derives many benefits from natural ecosystems, ecosystem services include water purification, soil fertility and climate regulation. Ecosystems are home to cultural, intellectual and spiritual activities, some extractives such as fish, biomass, precursors for industry, are pillars of the household economy [Gretchen D. & Shamik D., 2001]. Knowledge about the quantity and diversity of species present in an area is linked to natural resource conservation efforts and implementation of appropriate management practices.

According to Gudiño [2025], the national territory is conformed by a geological mosaic with various ages, origins and topography which promotes the diversification and endemism of lineages derived from geographical barriers, and their subsequent divergence due to isolation and climate.

Freshwaters account for approximately 0.009 % of the planet's water, most of these habitats are shallow, receive abundant sunlight, and nutrients from runoff or discharges, therefore highly productive and abundantly capable of sustaining life. Lakes are created and affected by climatic and geological forces, such as droughts, floods, earthquakes, landslides, among others. Each lake can be relatively isolated from others, meaning genetically distinct populations can evolve into new species. According to Gene [2001], freshwater habitats are perfect for the specialization process.

Fish account for more than 50% of the world's vertebrate biodiversity, according to Espinosa-Perez [2014], there were 2,763 registered species in Mexico, accounting for 9.8% of the species [both marine and freshwater].

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Of the nationally recorded species, 505 are freshwater. Aquatic vertebrates [fish], are characterized by gill breathing, lateral line, scales and their coloration is a function of the ecosystem they inhabit and their predators.

The presence of dead endemic fish floating in Cajititlán Lagoon is a recurring problem, with mass mortality events documented in 2013, 2014 and 2022. The 2014 event was particularly severe, with records of 340 tons of dead fish. Nevertheless actions aimed at harnessing these fish for compost making has proven to be an effective strategy to decrease the environmental and health impact of the situation. The dead fish were identified as *Goodea atripinnis*, a species characterized by its ability to adapt to eutrophic [nutrient-rich] waters. These fish are ovoviviparous and feed on mud from the water bottom [Juarez, 2023].

In September 2022 Toledo, reported the presence of dead tilapia in addition to Goodeas, it is estimated that approximately 50 tons of lifeless fish were removed. In accordance with the data reported by Vizcaíno et al., 2017 a high ratio of cyanophytes: *Microcystis* and *Anabaena* spp was observed associated with fish mortality during the summer.

Other researchers suggest that the low levels of oxygen in the lagoon, as well as the abundance of cyanobacteria with the ability to produce toxins are considered the main factors of the environmental deterioration of the lagoon which leads to the death of fish [Ocampo-Alvarez and col., 2020].

Auned to the pollution of water bodies resulting from anthropogenic activities, the accidental or deliberate introduction of non-native organisms with the ability to monopolize freshwater habitats leads to the extinction of native and endemic lake species [Sand-Jensen, 2024].

The term biodiversity includes variability of genes, species, and ecosystems as well as the services they provide to biological systems [Nuñez et al., 2003].

Hence the loss of biodiversity can be cataloged at three levels, ecosystems, species or genes and one of the most relevant issues is its conservation.

Human actions cause the decline of the diversity of life in the lagoon, visible in the reduction and simplification of populations, this serious situation drives an increased interest in the conservation of our biological wealth, know its origin and the cause of its decline. The natural heritage considered a common good of humanity possesses an incalculable value, its loss is the most transcendental and irreversible effect of our activities as it represents the disappearance of unique evolutionary processes and we must act to stop it.

Therefore the present work is being carried out in the Cajititlán Lagoon, aims to know the biodiversity of endemic freshwater fish species present with the aim of this being valued and known before their loss [Vizcaíno y col., 2017]. Endemic fish populations decline due to habitat destruction or are replaced by exotic species. The ignorance about the current population status and the apparent lack of interest in their conservation put these species at risk. It is important to establish projects for their conservation and recovery and to promote their cultivation for commercial purposes.

For this study the gene encoding for cytochrome b was considered, it is a powerful tool in evolutionary genetics, biodiversity and conservation has a highly conserved sequence, with enough variability between species. It is used to study genetic diversity.

A point diagnosis of endemic fish to the Cajititlán Lagoon was carried out, this benchmark study will facilitate the assessment of potential environmental impacts and allow decision-making in case necessary. Hence this work will lay the foundations for carrying out the molecular study of species and their correlation with morphology.

Methodology

Diagnosis: lymnological monitoring was carried out in the Cajititlán lagoon during the months of October, November and December 2024, from which juvenile samples were recovered from endemic species. The species classification was performed in the laboratory of Biotechnology of the Polytechnic University of the Metropolitan Area of Guadalajara and subsequently images were sent to the University Center of the South for typing, they were classified based on their morphology. See Figure 2.

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Box 2

Figure 2
Lagoon of Cajititlán, Jalisco Mexico.
Source [Ponce A., 2025]

International Nucleotide Sequence Database Collaboration NCBI and Blast [Basic Local Alignment Search Tool] was selected as reference for dendrogram elaboration. The cleaning of the sequences was performed visually, with respect to the conserved sites. Diagrams from NCBI were used. [Thompson et al., 1994; Hall, 1999; Tamura et al., 2013].

Results

Box 3

Figure 3
Cajititlán Lagoon Phytobioremediation Island

In Figure 3 was taken from the malecón of the Cajititlán Lagoon, an island of phyto-bioremediation and animal species inhabiting the water body is observed.

Freshwater environments are classified into waters with current [lotic environments: rivers and estuaries] and waters without current but with wind-generated waves [lentic environments: which include lakes, lagoons, swamps] [Vizcaíno et al., 2024].

In Figure 4 some of the specimens collected for their classification are observed.

Among the sweet-aquatic species in Mexico stand out those that are in the risk category according to NOM-059-Semarnat-2010 and constitute 37.2%. Mexico is considered a mega-diverse country and of the group of vertebrates, the richness of fish is estimated at 2,763 species and these account for 9.8 % of the known fish in the world [Espinosa-Perez 2014].

Box 4

Figure 4
Fish specimens recovered from the Cajititlán Lagoon in the December 2024 lymnological monitoring

Once the recovered fish were morphologically classified, the following species were identified: *Chirostoma jordani Woolman* [endangered, common name Charal] *Godea atripinnis* [Tiritos or panzoncitos] in Danger of Extinction. *Algansea Popoche* [popochas] Amenazada and as well as diversity or species of the genus *Goodea*. see Figure 5.

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Box 5

Figure 5
Biodiversity of Endemic Species from the Cajititlán Lagoon in the December 2024 lymnological monitoring

Our results agree with Espinoza-Perez [2014], fishes are difficult to describe due to the great diversity of characteristics and evolutions acquired over millions of years. Within these features include the number and distribution of scales [cycloid, ctenoid, rhomboid], the shape of the fish [fusiform, round, elongated, perciform, flattened].

The coloring [bright, metallic, transparent, dark, light, iridescent colors], ornamentation [in the form of bands, stripes, specks, birds, polka dots], the type of spines [needle shapes], eyes [present or absent] and the size. Some species migrate and tolerate different concentrations of salinity, temperature, pH and light intensity. According to literature fish can live between 1 and 120 years.

Our results agree with those reported by Canals et al., 2010 who mention the presence of "popocha" [*Algansea popoche*] with endemic distribution in the Lerma-Chapala basin and the Rio Grande de Santiago with Threatened status [A].

According to Caro et al., 2017, the fish species inhabiting the Cajititlán Lagoon include the "charal" [*Menidia Grudocule*], the lodero or popocha [*Goodea atripinnis*] and the pintitas [*Posiliopisinfans*].

According to Canales et al., 2010, the population of *Algansea popoche*, was very abundant in Lake Chapala and declined from 1938 and 1970 presumably due to overweight, since their turnover was estimated in canoes or hundreds, their current abundance is unknown. As a filter fish, it actively participates in the resuspension and loading of nutrients to the aquatic system, which benefits primary producers and the entire trophic chain of the lake.

This species is susceptible to infections caused by protozoa, parasites, wastewater, industrial and municipal pollution in addition to predation by exotic species, or water withdrawal during dry seasons. According to the literature it is considered on the verge of extinction [in Lake Chapala]. It is listed in NOM-059-SEMARNAT-2010 under the category of threatened species and currently lacks commercial importance.

Chirostoma Jordani Woolman are known as white fish or charales, is an endemic species of the Mexican Republic. Inhabiting freshwater, its highest production is recorded in Michoacan [Lake Pátzcuaro], Jalisco [Lerma-Santiago basins, Améca, Magdalena] and the State of Mexico. Their consumption is pre-Hispanic in origin, they form part of artisanal fisheries and the production volume in 2016 is presumed to be 11,757 tons.

The genus includes 25 species belongs to the family Atherinopsidae, has Endangered status, is considered at risk due to anthropogenic factors, predation, pollution, parasitism, competition for zooplankton and overexploitation. The charal usually feeds on plankton, benthos and pastures [Espinoza et al., 1993; Vazquez et al., 2013; Navarrete., 2017].

Goodea atripinnis Jordan "tiro" is recognized as an endemic species of the Lerma Santiago Basin, with distribution along the Mexican Pacific slope, is an omnivorous fish inhabiting springs, wetlands, lagoons, streams, large rivers and other deep-water habitats.

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It lives in waters at depths of 0.5 to 1.7 m in slow-moving areas, with neutral or alkaline pH, tolerant of clear or turbid waters with substrates of mud, clay, sand, gravel and rocks with abundant aquatic weeds. It feeds on higher vegetation, filamentous algae, mainly *Chlorophyceae* and companion fauna [Crown 2015]. The family *Goodeidae* is divided into two subfamilies: *Empetrichthynae* and *Goodeinae* the latter represented by 19 genera and 41 species is characterized by internal fertilization [viviparity]. Species reported for Mexico from the family *goodeidae* include varieties of *Alldontichthys, Allophorus robustus, Allotoca*. [Vazquez et al., 2018].

In the Mexican official standard NOM-059-SEMARNAT-2010 the genus *Goodea* is in the category of Endangered Species. [CONCIBO. Normative Annex III [List of species at risk].

Higher similarity between *Goodea atripinnis* and *Allotoca diazi* is observed in the dendogram of Figure 6, which share a common ancestor. These species showed higher similarity to *Chirostoma Jordani*, suggesting a closer evolutionary relationship, with respect to the species recorded in *Algansea* which are more evolutionarily distant.

Box 6

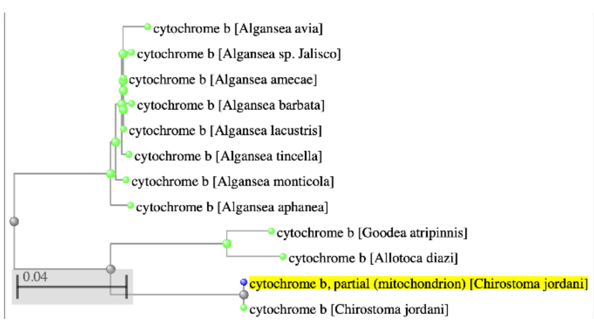

Figure 6

Dendogram of endemic Fish identified in the Cajititlán Lagoon in the December 2024 lymnological monitoring

Our results agree with those reported by Navarrete 2017, the loss of species diversity includes: hunting, species trafficking, wildlife capture and pest control techniques. Genetic diversity appears to be affected by the introduction of exotic species, which displace native ones due to competition, predation, habitat modification, introduction of diseases, the loss of germplasm and the release to the environment of genetically modified organisms.

Water bodies can also be classified into oligotrophic characterized by low nutrient and low primary productivity and eutrophic with high nutrient and high primary productivity [abundant algal growth] with low oxygen levels at night.

Animals that live on the surface of the water are classified as: neustons, those that live suspended in the water column [plankton], and those that swim actively [nekton]. Bottom-dwelling freshwater animals are classified as benthos [Hanson et al., 2010]. In the Cajititlán Lagoon, zooplankton that serve as the secondary link in the trophic chain and are food for fish include *Daphnia ambigua* and *Diaphanosoma birgei* [cladoceras], *Arctodiaptomus dorsalis*, *Leptodiaptomus siciloides*, *Mesopoocycloides* and *Mesopoocyclops edas*. [copepods]. [Velazquez-Ornelas, 2021].

It is worth mentioning also that tardigrades, which inhabit the limnoterrestrial or freshwater environments, based on the constant nutrient availability of surface water favors their development and present a favorable diet depending on the species, managing to be carnivorous, herbivorous or omnivorous. Carnivores feed primarily on protozoan organisms, nematodes, rotifers, and even other tardigrades, while herbivores on microalgae, plant fluids, and photosynthetic cells [Castañeda, 2025]. The third link in the food chain includes fish. In Mexico, approximately 500 species of freshwater fish have been recorded [54% of which are endemic]. In the Cajititlán lagoon, exotic fish species such as tilapia [*Tilapia nilotica* and *Oreochumis aurea*], mentioned by Perez-Rojas, de Luján et al. [2019], can also be found.

These species have the potential to compete with, displace, and even prey upon native species in the ecosystems where they have been introduced.

According to the author [mentioned by fishermen] the tilapia preyed on the catfish, carp and small fish [Perez-Rojas, 2019]. The use of species-level bioindicators in tropical countries, is sometimes impossible due to their diversity and adaptation to polluted environments, the scarcity of expert taxonomists, the lack of descriptions in the immature stages and taxonomic keys. [Springer, 2010].

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Huaquin, 2005 suggests integrating and extending teaching in ichthyology in basic and secondary training, as a measure to improve informed decision-making in relation to the conservation and sustainable use of resources, mentioning that its purpose is to record, analyze and classify fish of commercial interest.

The concept of sustainable development is based on using available resources in a sustainable way so as not to affect future generations. When the balance is broken due to misuse, environmental degradation occurs which is a process of the deterioration of ecosystems [CNDH, 2016]. Its effect is observed in climate change, which is characterized by high levels of factors such as: CO_2, surface water temperature and sea level volume derived from polar and glacier thaws. Soil erosion: by loss of vegetation cover due to land use change, habitat fragmentation [caused by over-exploitation of oil, gas or groundwater] and water pollution [Vizcaíno,2024].

Mega-diverse countries should develop biological diversity conservation programs, environmental policies and effective legal systems. influenced by cultural practices, economic and development policies [CNDH, 2016].

There are threats to the life cycle of endemic species in the lakes, affecting their reproductive success and population size, the introduction of new species, the extraction of water for irrigation, uncontrolled fishing, can be considered a massive threat but it does not accumulate. consequences and environmental impact [Vizcaino et al., 2024].

All ecosystems are composed of species with functions in the trophic chain, the primary link of the chain are microalgae and cyanobacteria that use suspended organic matter, nitrogen and phosphate ions, as well as solar energy to perform carbohydrate synthesis. and proteins. Microalgae are the food of zooplankton populations that also spread massively stimulated by the abundance of microalgae and are a source of chemical energy for filter fish [Hanson et al., 2010; Vizcaíno et al., 2024].

When there is an excess of chemical energy accumulated in the system and there is no outlet for the same, an environmental imbalance occurs which causes the death of species.

Eutrophicated water bodies with high nutrient content are highly productive, the mass production of algae, zooplankton and muddy fish if not used or extracted in the water body accumulates in the system and an excess of chemical energy translates into unacceptable conditions.

It is therefore necessary to establish periodic or seasonal monitoring systems of the relative abundance of populations of endemic species and their exploitation for commercial purposes or in the production of biomass and energy. On the contrary, the oversaturation of the ecosystem threatens the most fragile species [lottery sins], the unawareness and apparent lack of interest in their conservation accentuates the problem with direct effects on the ecosystem and the population.

Conclusions

The species *Chirostoma jordani Woolman* "Charal," classified as endangered, was identified, as well as *Goodea atripinnis* "Tiritos or panzoncitos," also endangered, and *Alganesa Popoche* "popochas," with a threatened status. Given the great diversity of species of the genus *Goodea* inhabiting the Cajititlán lagoon, it is necessary to monitor their populations and ensure their sustainable use; otherwise, the excess of organic matter [chemical energy] puts the sustainability of the wetland at risk.

Declarations

Conflict of interest

The authors declare that there is no conflict of personal or financial interest influencing the writing of the present article.

Author contribution

Vizcaíno-Rodríguez, Luz Adriana: Contributed to the Project development, methodology, technique and writing.

García - Vizcaíno: Contributed to data analysis.

Michel-Parra, J. Guadalupe: Contributed to species identification.

Caro-Becerra, Juan Luis: Contributed in financing.

Availability of data and materials

Indicate the availability of the data obtained in this research.

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Abbreviations

NOM-059-SEMARNAT-2010	Norma Oficial Mexicana, Protección ambiental-Especies nativas de México flora y fauna silvestres-categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-L-Lista de especies en riesgo.

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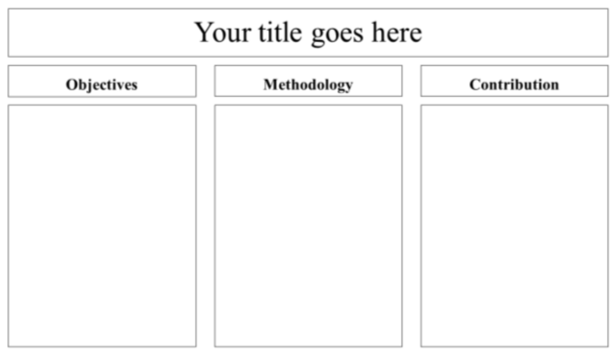

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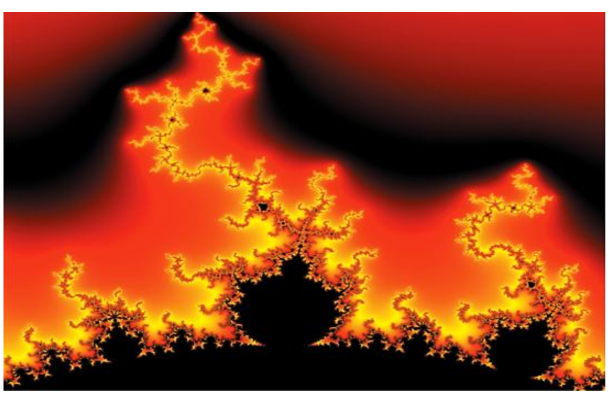

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Table 1
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For the use of equations, noted as follows:

$$Y_{ij} = \alpha + \sum_{h=1}^{r} \beta_h X_{hij} + u_j + e_{ij} \quad [1]$$

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Methodology

Develop give the meaning of the variables in linear writing and important is the comparison of the used criteria.

Results

The results shall be by section of the article.

Conclusions

Clearly explain the results and possibilities of improvement.

Annexes

Tables and adequate sources.

<u>The international standard is 7 pages minimum and 14 pages maximum.</u>

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The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

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Author contribution

Specify the contribution of each researcher in each of the points developed in this research.

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Benoit-Pauleter, Gerard: Contributed to the project idea, research method and technique.

Availability of data and materials

Indicate the availability of the data obtained in this research.

Funding

Indicate if the research received some financing.

Acknowledgements

Indicate if they were financed by any institution, University or company.

Abbreviations

List abbreviations in alphabetical order.

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ANN	Artificial Neural Network

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