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Journal of Environmental Sciences and Natural Resources

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Support the international scientific community in its written production Science, Technology and Innovation in the Field of Biotechnology and Agricultural Sciences, in Subdisciplines of agriculture-forest, pathology-sustainable, horticulture, fisheries and aquaculture, agricultural biotechnology.

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Knowledge Area

The works must be unpublished and refer to topics of agriculture-forest, pathology-sustainable, horticulture, fisheries and aquaculture, agricultural biotechnology and other topics related to Biotechnology and Agricultural Sciences.

Presentation of content

In the first article we present, *The potential of microalgae for the development of innovative technologies for the protection and preservation of the environment*, by GALLEGOS-GARCÍA, María Irene Liliana, PÉREZ-AGUILAR, Nancy Verónica, OYERVIDES-MUÑOZ, Ernesto and GALLEGOS GARCÍA, Marisol, with adscription in the Universidad Autónoma de Coahuila and Universidad Autónoma de San Luis Potosí, as next article we present, *Use of the quality function deployment tool for the design of a humidity transformer system in drinking water*, by BARBOSA-MORENO, Alfonso, MAR-OROZCO, Carlos Eusebio, BARBOSA-MORENO, Gabriela and OROZCO-CUERVO, Ulises de Jesús, with adscription in the Instituto Tecnológico de Ciudad Madero, as next article we present, *Effect of sowing speed on germination percentage in corn crop (Zea mays)*, by RODRÍGUEZ-MARTÍNEZ, Nellybeth, CALLEJAS-HERNÁNDEZ, Judith, BUSTAMANTE-ESPINOSA, Laura Virginia and RODRÍGUEZ-ORTEGA, Alejandro, with adscription in the Universidad Politécnica de Francisco I Madero, as last article we present, *Preliminary list of diurnal butterflies in the Vega de Metztitlán, Hidalgo*, by MARTÍNEZ-SÁNCHEZ, Itzcóatl, SÁNCHEZ-REYES, Uriel Yeshua, MARTINEZ-LARA, Filiberto and SILVA-MARTINEZ, Karla Lissette, with adscription in the Universidad Politécnica de Francisco I. Madero.

Content

The potential of microalgae for the development of innovative technologies for the protection and preservation of the environment

El potencial de las microalgas para innovar las tecnologías para el cuidado y conservación del medioambiente

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Abstract

Microalgae are mainly known for their high nutritional value, protein and lipid content. They are used to enrich animal feeds and are recommended as food supplements in the human diet. Nowadays, it is possible to design the cultivation conditions of microalgae in order to produce them with the specific characteristics desired. Since this is so important, the aim of this work is to present the progress made by different research groups on the best cultivation conditions to optimize the intensive production of microalgae. It also presents the most recent lines of research on the use of microalgae for the care of the environment, their potential application in the remediation of air pollution, as well as their use in the removal of various toxic substances in water. The methodology used was to make an exhaustive bibliographic review of books, journals, theses and articles on the subject, showing in a simple, clear and summarized way that microalgae are an option of 100% natural use of multiple benefits in the protection and restoration of ecosystems, in addition to being a sustainable alternative to other technological options for the remediation of water and air pollution.

Cultivation, Biofuels, Environmental remediation

Resumen

Las microalgas son reconocidas principalmente por su alto valor nutricional, contenido de proteínas y de lípidos, son utilizadas para enriquecer alimentos para consumo animal y se recomiendan como suplemento alimenticio en la dieta del ser humano. En la actualidad, es posible diseñar las condiciones de cultivo de las microalgas para producirlas con las características específicas que se desean. Siendo esto tan importante, el objetivo de este trabajo es presentar los avances obtenidos por diferentes grupos de investigación sobre las mejores condiciones de cultivo para optimizar la producción intensiva de microalgas. También, se presenta las últimas líneas de investigación del uso de microalgas para el cuidado del medio ambiente, su potencial aplicación en la remediación de la contaminación del aire, así como su uso en la remoción de diversas sustancias tóxicas en el agua. La metodología empleada fue hacer una revisión bibliográfica exhaustiva en libros, revistas, tesis y artículos sobre el tema, mostrando de manera sencilla, clara y resumida que las microalgas son una opción de uso 100% natural, de beneficio múltiple para el ser humano, alternativa sustentable frente a otras opciones tecnológicas como biocombustible y como parte en la remediación de la contaminación del agua y del aire.

Cultivo, Biocombustible, Remediación ambiental

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Introduction

Biotechnology has become a fundamental tool to study the biochemistry and functionality of microalgae for biomass production, and it has been found that they have higher photosynthetic performance than plants and algae, resulting in higher biomass production capacity with high nutrient and lipid content (Lu *et al*., 2021; Araújo *et al.,* 2021; Liu and Benning, 2013). Therefore, they have attracted the interest of many researchers who are looking for alternatives and solutions to various environmental pollution problems, both air and water, using simple, economical and efficient processes, in addition to the recycling of residuals and the production of clean energy (Cheirsilp *et al.,* 2023).. Intensive cultivation of microalgae can contribute to the reduction of CO_2 emissions from power plants, consume inorganic nitrogen and phosphorus (Bernard, 2011; Benemann, 2003), recycle pollutants present in water or air and adsorb them for the production of biomass that acts as a completely environmentally friendly biofuel (Cheirsilp et al., 2023; Silambarasan *et al.,* 2020;; Hernández and Labbé, 2014), making them an excellent option as an energy source for the future (Subhash *et al.,* 2013; Bernard, 2011).

This review presents the most relevant information on microalgae, from the components of their cellular structure and the functions they perform, to understanding the processes and favorable conditions for their cultivation, which lead to the production of certain biomass components that are of high value for some specific industries. Also included are the advances in biotechnology that have allowed the development of new technologies and the benefits associated with their low cost. This information is complemented by recent research demonstrating the potential of microalgae in the areas of health, environment, energy and food production.

For example, in disease prevention (Agudelo, 2020, Malagón *et al.,* 2017, Castrillon *et al.,* 2013), treatment of chronic diseases (de Morais *et al*., 2010), creation of cosmetics (Wang *et al*., 2015), production of biofertilizers (Silambarasan *et al.*, 2020; Singh *et al.,* 2019), animal feeding (Hernández y Labbé, 2014; Castrillon *et al.*, 2013) and aquifers (Pachiappan *et al*., 2015; Lenihan *et al*., 2013), as adsorbent for metals and toxic substances (Leong, 2020; Sayadi *et al*., 2019; Malakootian *et al*., 2016), for wastewater remediation (Ranjan *et al*., 2019; Young *et al*., 2019), in the conversion of wastewater nutrients into biomass for biofuel production (Singh *et al*., 2019, Khan *et al*., 2018) and especially as a great alternative for bioenergy (Michelon, 2021) even for households (Silambarasan *et al.*, 2020; Pérez et al., 2019), transportation and industry (Shin *et al*., 2019), in the creation of biorefineries (Araújo *et al.*, 2021)), as a strategy for what is produced in the field for sustainable food (Araújo *et al*., 2021) and all this without affecting the environment (Chen *et al*., 2016; Benemann, 2003).

Structure of microalgae

Microalgae are known by phycologists as microscopic organisms, measuring between 2 and 200 µm, and are established within the taxonomy of the animal kingdom of the eukaryotes mainly because they have a defined nucleus and organelles to perform different functions in their cell, they show DNA replication, contain chlorophyll *a* and form an undifferentiated vegetative body (Tomaselli, 2004). An exception to this classification are cyanobacteria, which, although prokaryotic, are smaller than eukaryotes, cells without a nucleus and without organelles; they also show DNA and RNA replication distributed throughout their structure. Their morphology and function are similar to that of algae, which also contain chlorophyll pigments, are capable of photosynthesis, and are responsible for the production of 50% of O_2 and CO_2 fixation on our planet (Brunet *et al.*, 2021). Figure 1 shows sections of the cell structure of a microalga (1a) and a cyanobacterium (1b) showing the main differences in size and internal structure. One of the structural characteristics of microalgae is that they can be unicellular, colonial or filamentous.

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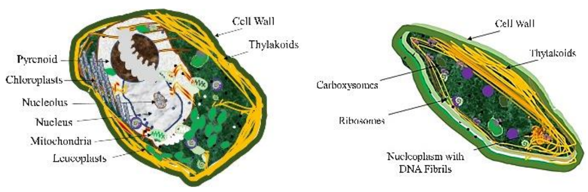
Some have motility due to the presence of flagella, and although in the case of cyanobacteria they can be unicellular and have no flagella, they have some motility that occurs through sliding movements due to mucilaginous substances that they release, allowing them to swim in liquids and on surfaces (Tomaselli, 2004). Colonies can be motile as long as they have flagellated cells and are embedded in mucilage, otherwise they lack motility.



(a) (b)

Figure 1 Structures of microalgae: a) *Chlorella vulgaris* and a cyanobacterium, b) *Synechococcus* spp.
Source: (Images based on micrographs by M.R. Palandri in Richmond, 2004)

An example of filamentous microalgae is the cyanobacterium *Spirulina* or *Artrosphira platensis* and it should be noted that it contains a four-layered gram-negative cell wall, where the structural part is a layer of peptidoglycan or murein, which is very resistant, it also gives shape to the bacterium and protects it from cell rupture in aquatic environments. Outside, there is a layer of lipopolysaccharides or endotoxin, which is released upon solubilization, stimulating innate immune responses that provide protection against all antigens. Also, this microalga does not contain cellulose, so it can be recommended for human consumption, it is excellent as a food supplement and forms a defense system within the organism (Tomaselli, 2004). Another characteristic is its membrane formed by thylakoids with phycobilisomes attached to the protoplasmic surface that contain a natural pigment that transfers light energy to chlorophyll, called phycobiliprotein, which is widely used in the food, cosmetic and pharmaceutical industries (Mogollón, 2019; Lafarga, 2013). In addition, this microalga has been certified by the FDA (Food and Drug Administration) as a safe and nutritious food par excellence, since it contains 60-70% protein and amino acids, provitamin A, β-carotene and is rich in vitamin B12 ((Richmond, 1992). Microalgae can grow in environments as diverse as soil, various bodies of water, or open air (Richmond, 2004).

They are classified as having high photosynthetic efficiency, reports Subhash et al., (citing Cheng, *et al.*, 2006) due to their ability to fix up to 6.24 kg-m^3/day of CO_2 (Subhash *et al*., 2013), they grow rapidly even under extreme temperature conditions, in environments with high concentration of heavy metals, high salinity or with high production of biofuels and fertilizers (Sanchez *et al.*, 2020). It is worth highlighting that the main effect of microalgae is to improve water stability, quality and pH. They achieve this by breathing during the day and performing the photosynthesis process, in which they consume CO_2 and even some greenhouse gases such as NOx, this allows them to produce energy and release O_2, which increases the pH of the water depending on the intensity of illumination. During the night, the release of CO_2 occurs and consequently the pH decreases and some biosorption process may also occur (Benemann, 2003) (Figure 2).

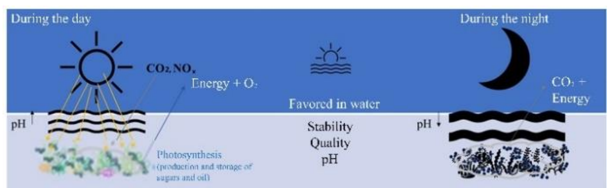


Figure 2 Conditions that favor photosynthesis by microalgae and consequently the production and storage of sugars and oils, as well as the effect on the pH of the water in which they are cultivated, Authors' Image

An important advantage of microalgae cultivation is its economic viability, since in a short time it is possible to have large quantities of biomass for different uses, making its cultivation more profitable than any other species, and currently its greatest contribution to human nutrition through food supplements and as animal feed. Proteins are the main component with about 50%, no other vegetable species or derivative of animal origin reaches the levels contained in microalgae; a special case is Spirulina with up to 70% of proteins, so it is considered an extremely complete food for growth, tissue strengthening, oxygen transport in the blood, among others. They also contain about 80% of lipids (on a dry basis), which allows them to store energy in organisms and improve their health, an example is the feeding of fish with microalgae to increase their nutritional value, resulting in a high proportion of omega micronutrients, almost the same proportion as a salmon, making this food affordable for the population.

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Another essential component is polysaccharides, which represent about 20%, being some of their functions to regulate glucose levels and prevent cell aging. In a smaller proportion is lutein, which is beneficial for visual acuity; phycocyanins improve the nervous system, have anticarcinogenic and anti-inflammatory properties, maintain cholesterol levels, are antioxidants and improve digestion. Beta-carotene improves vision and is an antioxidant; EPA and DHA improve blood pressure and heart function; astaxanthin is anti-inflammatory. Overall, microalgae biomass is a renewable energy source. Because of all these components and their biological and energetic importance, microalgae have been used in numerous applications ranging from pharmaceuticals, nutraceuticals of high nutritional value, high value chemicals, polymers, bio-oils, bio-fuels, as well as nutrient-rich fertilizers derived from biomass recovered from wastewater treated with microalgae.

Microalgae cultivation

Historically, the first microalgae cultures were made by Beijerinck (1890) with *Chlorella*, a microorganism of high commercial value, which was intensively cultivated for commercialization in Japan from 1960. In Mexico, cultivation began in 1970 and it was spirulina that was the first microalgae recognized worldwide, identified as *Spirulina maxima*, harvested in Lake Texcoco mentioned by Rout et al., (citing Ciferri., 1993) and used for human consumption (Acien *et al*., 2017; Rout *et al.*, 2015). However, one of the fundamental aspects that allowed its intensive cultivation for mass production was the establishment of a site with sufficient natural or chemical light sources to reduce production costs (Richmond, 2004). In 1977, the first commercial *Spirulina* plant was established in Thailand, which subsequently spread to such an extent that by 1980, there were already 46 factories in Asia producing more than 1000 kg of microalgae per month, mainly *Chlorella*, redacted by Perumal et al., (citing Kawaguchi, 1980), by 1996, they had reached 2000 tons marketed in Japan alone. In 1986, other facilities were installed in Australia, the United States, and Israel, and high production of cyanobacteria began in India (Pachiappan et al., 2015).

Much research into the uses of microalgae continued successfully, and around the first decade of the year 2000, the main requirements that an industrial facility must meet for efficient microalgae cultivation were established (Figure 3). First, the biochemical conditions of the microalgae are characterized at the laboratory level with the culture medium and the system operating variables. Then, the main parameters are considered such as: the concentration of nutrients (water, carbon, oxygen, nitrogen, phosphorus and mineral salts) in the culture medium, temperature, pH, light intensity, aeration rate, CO_2 addition, stirring rate, operating time, etc. (Costache, 2013). And finally, the appropriate production method is used to obtain the desired species and then scale up the results for mass production (Park *et al*., 2011).

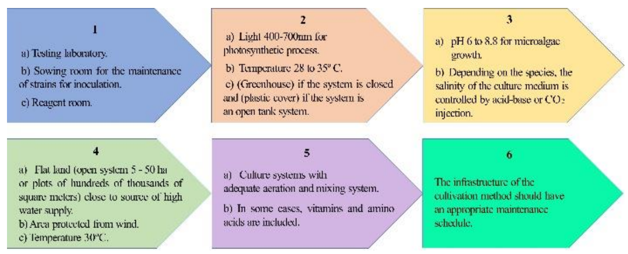

Figure 3 Requirements for efficient microalgae cultivation
Source: Authors' illustration

An example in the development of biorefineries explains the importance of choosing a geographical location with optimal conditions for the large-scale production of microalgae, mainly sufficient energy, nutrients and water, which allows the separation of different products from the biomass and the use of residual nutrient flows and CO_2 reduction (Moncada *et al*., 2015; Andersson, 2014; Young, 2019). In this sense, it is necessary to match the microalgae cultivation method with the site chosen for its production, which are categorized as open or closed systems, or the combination of both. Open systems include the use of fermenters or open-air ponds (Borowitzka, 1999). Closed systems are those that use photobioreactors regulated under certain control parameters (Jorquera *et al*., 2010). In the combination of microalgae production systems or also called semi-open systems, photobioreactors, ponds and fermenters are used, which currently represent 71, 19 and 10% respectively of the total production in Europe (Araujo *et al*., 2021). Open systems were the first industrial cultivation methods for microalgae.

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They consist of facilities called raceways, which consist of shallow ponds of different types and sizes depending on the species to be cultivated, with high resistance to adapt to hypersaline environments. The cultivation is done in a closed circuit where the cells can circulate, it includes inclination, laminar flow with the help of an air pump or paddle system to remain in suspension and thus receive sunlight and be able to perform photosynthesis (Guzman *et al.*, 2021). In this type of systems, *Spirulina, Chlorella, Dunaliella salina, Tetraselmis, Haematococcus* species, among others, are mainly cultivated (Costa *et al*., 2019). In some cases, however, the production in these systems is higher, both investment, operating and energy costs are lower, but there are disadvantages such as less control over environmental conditions, higher risk of contamination, higher requirements for land and especially water (Narala *et al*., 2016; Mayers *et al*., 2016). In response to these drawbacks, a cultivation technology in closed systems has been developed using photobioreactors, which allow a more efficient production of microalgae with specific characteristics, having different properties and materials to achieve high product stability, higher photosynthetic efficiency and low cost (Narala *et al*., 2016; Acién *et al*., 2017). On the one hand, there are the fermenters, there are different types of materials and shapes, with height from 1 to 2 times its diameter, there are from mini fermenters of 200 to 1000 mL for laboratory tests, to equipment usually of 700 L. In these, organic compounds can be used as a carbon source, there is greater control over all the variables in the process such as pH, temperature, aeration and agitation speed, nutrient concentration of the culture medium, the first phase of microalgae growth; higher productivity and lower costs can be obtained (Barros *et al*., 2019). The production of algae by this method starts with an inoculation in a laboratory flask, where the cells are grown and then transferred to a fermenter, where dense cell seeding is performed and then transferred to larger fermenters. An example is the use of fermenters for oil production from *Chlorella sp*. and *Schizochytrium sp*. (Lu *et al*., 2021), which is performed in three steps: 1) algae cultivation, 2) harvesting, and 3) oil extraction. As for closed photobioreactors, they consist of tubular systems or cylinders, either horizontal or vertical, connected in series or parallel to form the solar collector, they can also be flat in the form of sheets, sheaths or bags oriented to receive light.

These structures allow the isolation of pollutants from the environment and greater benefit in the production of high-quality biomass, with better photosynthetic production, therefore more concentrated crops (Eriksen, 2008). In photobioreactors it is possible to cultivate all year round, they have less evaporation losses, better temperature control, better continuous operation, for all these characteristics they are mainly used for the production of microalgae used in pharmaceutical, nutritional and personal care products (Guzmán *et al*., 2021). Photobioreactors vary in size from one to hundreds of cubic meters of culture volume for the production of kilograms per day and also in the type of material, which can be green walls, plastic or glass. The disadvantages of this system are the high cost of the equipment, the constant lighting, the need to control the operating conditions, as well as the energy requirements for aeration and/or agitation, the loss of CO_2 and, in some cases, the accumulation of oxygen (Fernandez *et al.*, 2016). An evolution of microalgae cultivation systems has been the combination of open and closed systems. In this case, photobioreactors are used in the first stage to avoid contamination of the culture medium and ensure a high quality of microalgae. The second stage consists of transferring the culture either to tanks or fermenters to achieve the total growth of the biomass with all its characteristics according to its type (Murthy, 2011). In terms of cost, biomass production can be less expensive in closed photobioreactors than in open ponds due to infrastructure, maintenance and labor costs (Arribas, 2020). Five stages can be identified in the microalgae growth process (Fernández, 2017; Acién, 2017) (Figure 4).

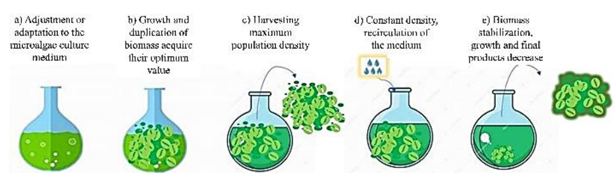

Figure 4 Growth stages of microalga
Source: Author's Illustration

It should also be considered that microalgae culture can be a) continuous, it is harvested when the culture medium is replenished, b) in batches, it is completely harvested at the stage of highest density and growth c) semi-continuous, which is a combination of a) and b), it is harvested according to production and the culture medium is replenished (Pachiapan *et al*., 2015).

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Microalgal growth is measured by counting the number of cells per milliliter using a microscope with a Neubauer and Palmer-Maloney (Manrique, 2019), chamber or a Sedgewick-Rafter counting chamber. In the latter case, the cell limits the area of the sample to be counted, is low-tech but efficient, and is also an economical technique (Garcés, 1984). Another possibility is to use indirect methods, although economically they are more expensive techniques, such as spectrophotometry, measurement by Secchi disks, measurement by Beckman Coulter flow cytometry (Gasol and Del Giorgio 2000), weight measurement by filtration and volume determination by centrifugation, among others (Figure 5).

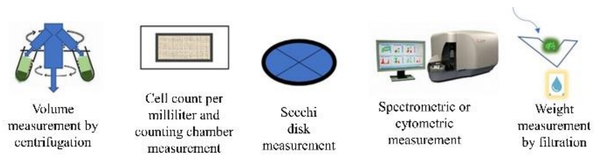

Figure 5 Direct and indirect methods to measure microalgae growth
Source: Author's Illustration

Finally, the harvesting of the crop varies according to the use that the microalgae will have, and to collect it different techniques are used: centrifugation, chemical flocculation, filtration, aggregate formation by ultrasound and flotation. For the commercialization of microalgae it is necessary to include refrigeration or freezing, in other cases they are dehydrated with atomization technologies, lyophilization, high pressure homogenization or ultrasound with cell rupture, others are treated with organic solvents for oil extraction and some are vacuum packed (Pachiappan et al., 2015). Figure 6 summarizes the different cultivation methods of microalgae and their main products. At the same time as progress has been made in the development of cultivation methods, research has been published on how to reduce the cost of microalgae production, for example, the cost of microalgae production from three companies working in different systems: open ponds, horizontal and flat panel photobioreactors, with costs of 4.95, 4.15 and 5.96 €/Kg respectively, and found that factors such as irradiation, mixing, photosynthetic efficiency, medium and CO_2, when optimized, resulted in a cost of 0.68 €/Kg, which favored microalgae as a raw material. In addition to having a future as a biofuel in aviation (Norsker *et al*., 2011).

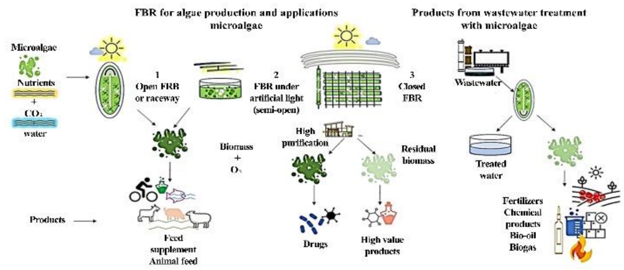

Figure 6 Microalgae production methods and their applications
Source: Author's Illustration

Another study presented a cost of 69 €/Kg for the production of 9 t/year of a high-value microalgae in tubular photobioreactors, which was improved by simplifying the technology and scaling up production to 200 t/year, significantly reducing the cost to 12.6 €/Kg, and it is still possible to improve it by reducing energy and labor consumption (Acién *et al*., 2012). Mayers *et al*. (Mayers *et al*., 2016) presented a literature review on the reduction and recycling of inputs and processes in microalgae production, with the aim of reducing production costs. In another study, Mayers *et al*. (*May*ers *et al*., 2017), which investigated the reuse of waste and waste nutrients from a food industry, the cost and environmental impact of nitrogen and phosphorus was reduced by 90% compared to the use of artificial fertilizers in the production of biomass and biodiesel in the microalgae *Nannochloropsis sp*. Chen *et al*. (Chen *et al*., 2016), showed the challenges and future prospects of microalgae production in China, which until then was the main producer of microalgae worldwide. Another good example is the study by Ranjan *et al.,* (Ranjan *et al.,* 2019), on environmental and wastewater operating conditions in high-speed algae ponds for biomass and biofuel production, highlighting that equipment design, biochemical approach and optimization parameters are the most important points to reduce production costs. Meanwhile, in Europe, the requirements of the Renewable Energy Directive for 2020 stipulate that at least 10% of the energy used in transport must come from renewable sources, that emissions must be reduced by 35%, and that biofuel production should not lead to the destruction of land with high biodiversity (Union, 2009).

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Current production of microalgae

An estimate of the amount of microalgae produced in Europe according to FAO (Food and Agriculture Organization) or Eurostat is 182 tons in dry weight, the most cultivated species are *Spirulina*, *Chlorella spp*. and *H. pluvialis* with 142 tons in dry weight (FAO, 2022.). In the report by Araujo *et al*. (2021), 16 European countries were identified with cultivation systems of different microalgae species and 15 countries specialized in the cultivation of *Spirulina*. Germany, France and Spain stand out as the countries with the highest production using photobioreactor systems (71%); France is the country that mainly cultivates *Spirulina* in production units (65%); on the other hand, Italy, Germany and Spain produce up to 83% in open systems. In other European countries, such as France, Denmark and Portugal, fermenter systems are used for the cultivation of 10% of the biomass recorded (Araujo *et al*., 2021). Studies conducted in Mexico on the production capacity of microalgae have estimated that 26.8% of the land in the south of the country, in the states of Jalisco, Oaxaca and Veracruz, is suitable for this type of cultivation, with a potential production of 3.8 million tons per year. However, as in Europe, Mexico continues to search for new locations, access, land ownership, soil resources, solar radiation, production profitability, etc. that favor the establishment of intensive microalgae cultivation. In addition to the above-mentioned costs of equipment, raw materials, labor, and processes, there are many political restrictions on the types of species to be produced and the quality parameters required for problem-free use, especially in food and medicine, *Lozano et al.,* (Lozano *et al*., 2019) present a paper on the identification of suitable areas for the construction of open pond biofuel production facilities. Persistence Market Research (PMR, 2021) is a repository of comprehensive information on research on various industrial products, and in the case of the microalgae market, they show the results and projections on the global demand for this product. PMR reported that the compound annual growth rate (CAGR) of microalgae-based products was 4.2% from 2016 to 2020 and is expected to grow to 5.7% for the global market from 2021 to 2031, as the world population's demand for healthier and natural products increases.

For its part, Chen *et al*. (Chen et al., 2016) also confirms that the annual growth of microalgae at the industrial level is 10%, with 30,000 tons per year worldwide. In monetary terms, this growth represents $2.76 million in 2020 as the market value of microalgae-based products, and the sales forecast for 2031 is $5.04 billion. The number of companies interested in the production of microalgae-based products is growing every day, and they are all committed to innovation and high quality in the development of their products: Naturex S.A., a company created in Mexico in 1997 with the support of Maver S.A. de C.V., is now a leader in the creation of nutritional foods and beverages, pharmaceuticals and personal care products, and has expanded with excellent results in France, Italy, Switzerland, Poland, England, Brazil, Chile and the United States. In 2019, the company tripled its production of *Spirulina* and launched a new product called Ultimate Spirulina, which allowed it to expand its product portfolio. Other companies are also forming alliances to support each other and grow exponentially in the market with microalgae-based products, for example: Nestlé S.A., a Swiss multinational food company considered to be the largest in the world, and Corbion N.V., a Dutch food and biochemicals company, partnered in November 2019. In 2020, Allmicroalgae Natural Products S.A. formed a joint venture with Greentech Group, a French biotechnology company, to expand its range of innovative products based on plant extracts, microorganisms and algae. For its part, Microphyt, a leader in the production and commercialization of active ingredients based on microalgae, has expanded its portfolio of nutrition and well-being products by investing $32 million (PMR, 2021). In recent years, the global agricultural industry has increased its production of feed for livestock, as the demand for meat increases daily due to the constant growth of the population. From a nutritional point of view, microalgae products offer higher levels of protein, omega-3 fatty acids, antioxidants, carotenoids and antimicrobial properties that help prevent diseases and improve animal growth. PMR's forecast for animal feed and aquaculture in this area extends its CAGR value of 4.8%, which in the stock market is US$4.40 million.

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Among the European countries, Germany is expected to have a growth of 14% in terms of market value, mainly due to the high number of geriatric population in this country, which in turn leads to a greater awareness of a better lifestyle and the consumption of superfoods. In Asia, the country with the highest demand for microalgae-based products is India, with a market share of 37%. Regarding the use of microalgae for the production of biofuels, the Intergovernmental Panel on Climate Change (IPCC) states that it is necessary to increase the percentage of bioenergy contribution in order to be able to think about the substitution of fossil fuels and thus contribute responsibly to the reduction of CO_2 emissions generated by them. As long as it is demonstrated that its conversion technology is truly efficient, viable and competitive (Brunet *et al*., 2021; Alam and Wang, 2019; Castillo *et al*., 2017; Moncada *et al*., 2015; Rashid *et al*., 2014; Andersson *et al*., 2014).The product with the highest global demand based on microalgae is lutein with a value share of about 19%. It is used as a skin aid to treat burns and reduce wrinkles, and in the food sector as a colorant for various products such as chicken, salmon, shrimp, crabs, and in egg production (PMR, 2021).For all uses of microalgae, it is important to note that there is some regulation. In Europe, for example, the use of microalgae in aquaculture is regulated by the Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA).The regulations are: Food Safety (EC Regulation 178/2002), Ingredients in Novel Foods (EC Regulation 258/97) and Nutrition and Health Claims on Foods (EC Regulation 1924/2006). In the United States, two laws apply to microalgae-based food and feed, the Federal Food, Drug and Cosmetic Act (FDC) and the Dietary Supplement Health and Education Act (DSHEA), which covers dietary ingredients and dietary supplements (Shah *et al*., 2018).The major manufacturers of microalgae-based products, accounting for 50% of the market share, are: Parry Nutraceuticals, a division of Eid Parry, part of the Indian company, Murugappa Group, founded in 1900 and valued at $5300 million, with more than 42 years of experience and a high production of *Spirulina*, DIC Corporation, a company of fine chemicals, inks and organic pigments, among others, founded in 1908 and operating in more than 60 countries worldwide.

For its part, PMR (PMR, 2021) notes that although the demand for microalgae production is increasing and the global market is valued at $ 3 billion, it is projected that sales in 2031 will increase at a compound annual rate of 5.7% by 2031, valued at more than $ 5 billion, but there is still much to be done, more technological development is needed to reduce the cost of the process and without compromising the high quality of the products, so that they can be competitive in every way with the products that exist in the market.

Uses and types of microalgae

There are more than 50,000 species of microalgae (Rashid *et al.*, 2014) with extraordinary properties for different types of applications depending on the species. However, only 20 of them have been studied in depth. The most common applications of microalgae are: 1) in aquaculture as the main source of aquatic organisms, some examples are *Nannochloropsis spp, Dunaliella spp, Chaetoceros spp, Pavlova spp, Isochrysis spp, Tetraselmis spp,* (FAO, 2021). These types of microalgae do not produce toxins, so it is important to know how to differentiate the type of strains between toxic and non-toxic in order to use them as food or food supplement; 2) in water purification, since they are capable of adsorbing heavy metals, dyes, and even nitrogen and carbon compounds that reduce eutrophication and at the same time serve as an indicator and prevention of water pollution due to their adsorption capacity and affinity for molecules and toxic substances, an example of this is *Tetraselmis sp*. (de Alba and Pabello, 2021; Alam and Wang, 2019;). 3) In agriculture as biostimulators of plant growth, an example of this is cyanobacteria, which are capable of producing biomass to provide a sustainable solution to soil fertility problems (Singh *et al*., 2019). 4) In biomedicine and pharmacology, used as a food supplement and in disease prevention (Hernández and Labbé, 2014), for its high content of iron, macro and micronutrients such as calcium, phosphorus, magnesium, sodium, nitrogen, sulfur, manganese, zinc, copper, iodine, cobalt. As a source of proteins, Spirulina sp. contains 50-70%, others are *Arthrospira maxima, Chlorella sp., Dunaliella salina* and *Dunaliella bardawil,* capable of regulating some functions of the nervous, hormonal and immune systems, as well as helping to reduce cholesterol.

Chlorella can also lower hemoglobin and blood sugar levels. Some species contain omega-3 and omega-6 fatty acids that prevent heart and neurological problems, cancer, and hypertension (Santos *et al.*, 2016); antioxidants such as astaxanthin, mainly from *Haematococcus*. Some microalgae such as *Spirulina* contain alginic acid and through the chelation process they can react with some metals such as lead, which is beneficial to be able to eliminate them from the human organism (Basheer *et al.*, 2020). Others such as *Dunaliella salina* are beneficial due to their content of oxidized carotenoids, which are anticarcinogenic, antimicrobial, excellent as anti-inflammatory and used in wound healing, as well as to help in the healing of stomach ulcers. Microalgae are characterized by their ability to produce from simple compounds, carbohydrates, lipids, proteins and secondary metabolites better known as antibiotics for their antibacterial, antifungal, antibiotic and antitumor properties (Basheer *et al.*,, 2020). 5) In the chemical and food industries, as microalgae participate in the biosynthesis and production of vitamins, polysaccharides, fatty acids, amino acids, waxes, prostaglandins, pigments such as phycobiliproteins that can be obtained from the *Rhodophyta Porphyridium* and *cyanobacterium*, among others (Wang *et al*., 2015); 6) In purification processes, due to their high capacity to support and fix CO2 present in the medium, up to 50 times more than terrestrial plants, as an example: *Nannochloro psisoculata, Tetraselmis sp., Chlorella vulgaris, Dunaliella tertiolecta* and *Scenedesmus obliquuscon* (Leiva, 2017). 7) In the production of biofuels such as biodiesel, biomethane or bioethanol, since oleaginous microalgae provide their energy through their oils (lipids and triglycerides) and it is in this area that most of the efforts for the production of microalgae are focused, since it favors the bioeconomy as a replacement for fossil fuels, an example among other microalgae is *Chlorella minutissima* (Castillo, 2017; Singh, 2019).

Another topic that has gained great importance is the study of the microalgae-bacteria couple, since bacteria favor the growth and production of a microalgae metabolite with greater biotechnological power (Gonzalez and Bashan, 2021), for example: a) in the development of biorefineries to reduce CO_2 emissions (Mccollum *et al.*, 2018), b) in plant growth, the microalgae-bacteria union provides biofertilizers with nutrients of higher quality than when used individually (amino acids, phytohormones, vitamins, proteins, among others), making it possible to enrich soils with organic matter (Ronga *et al.* , 2019).

Research trends in the use of microalgae with environmental impact

In biorefining for fossil fuel substitution.

A review on the use of microalgae for biodiesel production (Castillo *et al*., 2017) reported that the yield of lipid production was about 60 m^3/ha/year, although the production cost of $5.8 USD/Kg is high. Therefore, other techniques for lipid extraction continue to be investigated, such as supercritical fluid methods, pulsed electric field, microwave, ultrasound, and transesterification, as well as dual-purpose systems that propose cost reduction and wastewater reuse. Among the microalgae that have been studied for their high lipid and oil content (1 to 90% dry basis) are *Chlorella, minutissima, Thalassiosira fluviatilis, Thalassiosira pseudonana.*

In the same field, several studies have published positive results using the combination of microalgae and bacteria. For example, Xue *et al*. (Xue *et al*., 2018) showed that 80 % of the C16 and C18 content in the fatty acids of the microalga *Chlorella vulgaris* cultured with *Stenotrophomonas maltophilia* favored the quality of the biodiesel produced.

Years later, a study by Fayyaz *et al*. (Fayyaz *et al*., 2020) claims that microalgae is a product that provides clean and sustainable energy. However, its commercialization remains without potential due to high production costs and low yields.

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Their research presents the compilation of different studies (from 2014 to 2019) on the use of genetic and metabolic engineering to edit and modify the genome of microalgae to improve the quality and quantity in biomass production, as well as carbon fixation, among others; lipid production stands out. For example: 64.25 % in *Chlamydomonas reinhardtii* (Shin *et al*., 2019) and 69 % in *Nannochloropsis oceanica* (Li *et al*., 2019), also in pigment synthesis, for example: they increased *xeazanthin* content 56 times in *Chlamydomonas reinhardtii* and β-carotene production 50 % in *Scenedesmus sp.* CPC2. (Chen *et al*., 2017). These and other results demonstrate the potential to increase biofuel production capacity in biorefineries, reduce their costs by up to 20 %, and increase capital through the sale of high-value co-products, making this technology viable to increase the use of biofuels.

In air pollution remediation

Another work, such as that reported by Lu *et al*., (Lu *et al*., 2021), showed that it is possible to obtain oil from microalgae through heterotrophic fermentation; they stated that this oil would be an excellent substitute for fossil fuels, with an impact on the reduction of air pollutant emissions. Four different sugars were tested for fermentation and it was shown that heterotrophic fermentation had less impact than autotrophic fermentation. In addition, they showed that there is a balance between the yield rate/productivity of algal oil, obtaining a high density of algae in a short time, which can favor the increase of biofuel production.

In water pollution remediation

Of particular interest is the potential to eliminate toxic environmental pollutants in wastewater with the use of microalgae, for example, it has been used: in swine waters rich in nitrogen and phosphorus, with the subsequent use of the recovered biomass as feed for pig growth and it was also evaluated as an efficient eliminator of several antibiotic substances (tetracycline totally eliminated in 11 days) used in veterinary treatment (Michelon, 2021).

Another study presented by Castro (Castro, 2021) shows the use of *Spirulina* (*Arthrospira platensis*) for the denitrification of municipal wastewater, eliminating 13 % of nitrates and 55% of phosphates, which cause eutrophication and damage aquatic life. The study also points out that the treatment of this type of water is an issue that should be treated as a priority. In the same sense, according to data from FAO's Aquastat (FAO, 2022), only 52 % of water is recycled worldwide, and all untreated water is discharged into rivers, oceans, crops, etc., causing not only environmental degradation, but also the risk of critical diseases and even death in animals and humans.

Subhash *et al*. (Subhash *et al*., 2013) investigated the use of an oxygenated photo-biocatalytic fuel battery using atmospheric CO_2 and domestic wastewater as carbon sources to harness bioelectricity with mixed microalgae. Microalgae growth was 2.87 g/L, chlorophyll content was 5.12 mg/L, and electrogenic activity was 3.55 $\mu W/m^2$. Electrogenic activity was higher during the day than at night. Oxygen produced during oxygenic photosynthesis was found to be the main factor reducing the yield. The evaluation showed that the system is self-sustaining in terms of electricity and environmental remediation and can even be scaled up to the biorefinery level.

Combining microalgae with bacteria

Brunet *et al*., (Brunet *et al*., 2021) conducted research on the main methods of biogas purification in a biological way and its comparison with microalgae-bacteria consortia removing CO_2, H_2S, NO^-, PO_4^{3-} and metal ions that significantly affect the equipment using it. In addition, the biomass obtained from the oxidation of compounds has the characteristics to be used as biofertilizers and/or high quality biofuels and all on the same process without generating higher costs, being an economically viable option than others of physicochemical type.

Combining Microalgae and algae

A special case is the study by Silambarasan *et al*. (Silambarasan *et al.*, 2021), a work on the union of *Chlorella sp.* with *Scenedesmus sp.* algae, which proved to be beneficial in three applications: 1. biodiesel production, 2. domestic wastewater treatment, and 3. agricultural production.

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First, the algae combination obtained the highest biomass of 1.78 g/L, 27.03 μg/mL chlorophyll, 175 μg/mL protein, and 35 % dry cell weight in lipid content. The efficiencies of these algae to remove nitrate, ammonium, phosphate, chemical oxygen demand, organic carbon, and total nitrogen in 75 % dilute domestic wastewater were greater than 90 %. In addition, the biomass was tested as a biofertilizer in combination with inorganic fertilizers applied to tomato crops. In addition to macro- and micronutrients, an increase of almost 40 % in sprout and root dimensions, 95 % in fresh weight and 53 % in dry weight was recorded: 61 % N, 179 % P, 71 % K, 38 % Ca, 26 % Mg and 95 % Fe, with a benefit of 174 % in total tomato yield.

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Conclusions

This review presents the latest advances in research on microalgae of different species for their intensive cultivation and use in the fields of health, energy and environment, as well as the regulatory constraints that limit their production and use in different countries. In addition, some opportunities are identified for the research of different species of microalgae that have not been studied in depth, in order to assess the potential of these organisms that could trigger the creation of new technologies and innovations to improve human quality of human life, especially in aspects related to the care of the environment.

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Use of the quality function deployment tool for the design of a humidity transformer system in drinking water

Uso de la herramienta despliegue de la función de calidad para el diseño de un sistema transformador de humedad en agua potable

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Abstract

Water is a resource of vital importance for the life of living beings, the demand required is so great that in some areas of the planet it has begun to be scarce or to restrict use and consumption. In spite of the technological advances and the procedures to send this liquid, zones are detected in which the supply does not arrive, on the other hand every day the world population keeps increasing and generating a greater consumption of the same. The present study makes use of the deployment of a quality function better known as QFD as a way of listening to the voice of users and specifically determining the different aspects that must be addressed for the design of a moisture sensing device, as well as an estimation of the demand focused on the southern zone of Tamaulipas Mexico is also presented in order to know the potential market.

QFD, moisture collection, design engineering

Resumen

El agua es un recurso de vital importancia para la vida de los seres vivos, es tan grande la demanda requerida que en algunas zonas del planeta ha comenzado a escasear o a restringirse el uso y consumo. A pesar de los avances tecnológicos y los procedimientos para hacer llegar dicho líquido se detectan zonas en las que no llega el suministro, por otro lado cada día incrementa la población mundial generando un mayor consumo de la misma. En el presente estudio se hace uso del despliegue de función de calidad mejor conocido como QFD como una forma de escuchar la voz de los usuarios y determinar de forma específica los aspectos que deben ser atendidos para el diseño de un dispositivo captador de humedad, así como también se presenta una estimación de la demanda enfocada a la zona sur de Tamaulipas México con el propósito de conocer el mercado potencial.

QFD, captación de humedad, ingeniería de diseño

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Introduction

Water is a vital element for life on planet Earth, as it plays a decisive role in various biological, geological, meteorological, chemical and physical processes. (Blanca Jiménez Cisneros, 2010) The main form of atmospheric water is water vapour; when reference is made to the quantity of water vapour in the air, it is called "humidity". Having air as a source of origin, which is free and inexhaustible, and humidity that has very low amounts of mineral salts, allows obtaining high quality water (Jahan, 2015).

In rural communities in Mexico, access to purified water is lacking due to technological deficiencies, with consequences for people's well-being; the United Nations Development Programme (UNDP, 2015) indicates that around 1.8 million children die each year from diarrhoea, cholera, fever, polio, hepatitis and other diseases caused by unsafe drinking water and poor sanitation conditions.

70% of water vapour floats in the atmosphere as a result of evaporation from rivers, seas, plants and living things. Altitude, temperature, orography, geography and water masses are important factors that make water levels in the air very different across the globe. This vapour can be condensed naturally and artificially and in this way it is possible to transform the air into a source of drinking water.

Air contains different gases such as water vapour which is produced by the change of temperature and pressure, changing from liquid to gas. Conversely, if condensation takes place, the state changes from vapour to liquid through temperature change (Quintanilla et al., 2018).

The lack of water has as a consequence negative effects on biodiversity which subsequently has the effect that natural sources of water diminish. Due to water scarcity various consequences start to appear in the population such as: repercussions on health, hygiene, nutrition, lifestyle, etc. The lack of water has become an even more complicated challenge for low-income people, as these are usually the areas most affected by the lack of drinking water, thus leading this sector of the population to find their access to the natural resource very complicated or, failing that, the sources they use for their consumption are contaminated. (Úsuga, 2022).

According to the World Health Organization (2018) worldwide, around 3 in 10 people, or 2.1 billion people, lack access to safe and available water at home, and 6 in 10, or 4.5 billion, lack safe sanitation, according to a new report by the World Health Organization (WHO) and UNICEF (United Nations Children's Fund).

Contaminated water is responsible for the deaths of half a million people from diarrhoea each year. However, the problem is not only concentrated in poorer areas, but in richer countries, water in groundwater aquifers and watersheds is declining at a rate that is outstripping water replenishment (BBC News World, 2018).

On the other hand, there is the Quality Function Deployment tool known as QFD which is used for the design and development of a new product in the context of Total Quality Control.

Akao Yoji (1972) envisioned a deployment method that would address the important points to be taken into account during the design phase of the new product that would lead to the elimination of defective parts that would otherwise appear in the production phase.

Dr. Mizuno (1978) produced the first publication entitled "Quality Function Deployment". In it, he defined the methodology for carrying out QFD through the systematisation of objectives and means.

In the following, we will use this methodology to design a new product for the collection of humidity and which is capable of transforming this humidity into drinking water.

Methodology to be developed

Quality function deployment (QFD) is a methodology that translates customer requirements into a set of technical requirements, and does so at every stage of the design and production of a product or service (Garibay, Gutiérrez & Figueroa, 2010). QFD is often identified as the methodology for listening to the voice of the customer. QFD is considered a key tool for product development and for improving product quality in both service and manufacturing processes (Abu-Assab, 2012).

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Quality function deployment (QFD) is defined as: "the conversion of consumer demands into quality characteristics and the development of design quality for the finished product by systematically deploying relationships between demands and characteristics, starting with the quality of each functional component and extending the deployment of quality to each part of the process" (Zapata, 2013).

In the design phase, use was made of quality function deployment. In the first instance, the list of customer needs was made, consisting of 25 requirements that are essential for consumers to purchase such a system, among them are:

That the equipment captures enough moisture to obtain water, durable, the process is visible, easy to handle, easy to use, economical, white colour, does not consume light, firm structure, water quantity indicator, light, portable container, made with stainless materials, protection of the container, that it has visual appeal, easy to use, easy to maintain, not too ostentatious, portable, operation anywhere, good capacity, easy to move, resistant, not too bulky and finally that it can be adapted to any medium.

The requirements with the highest percentage were:

- That it captures sufficient moisture with 8.5%.
- Easy to use with 8.1%.
- Lightweight at 6.5%.
- Economical at 6.2%.

Once the client's requirements were finalised, the technical and operational characteristics, also known as "how to's", were made, which are shown below:

Optimal functioning, performance, materials, storage, design, absorption, weight, container protection, hardness, velocity control, filtering, visibility, tenacity, thermal conductivity, expansion, supply, foldability, durability, stability, size, minimum production cost, firmness, moisture control and filter adhesion.

For the construction of the roof, the correlation between the quality characteristics was evaluated, in which the following symbology was used:

┼┼ indicates strong positive correlation.

┼ indicates positive correlation

- indicates negative correlation

▼ indicates strong negative correlation

The optimal performance has a strong positive correlation with the materials as for the prototype to work it is necessary to use metals preferably, another characteristic that has a strong positive correlation is the size, as it can be neither too bulky nor too light.

Weight has a strong positive correlation with size, and a positive correlation with firmness. Size is another characteristic that has a strong positive correlation with absorption, as the blades need to be tall enough to capture the highest percentage of relative humidity present in the environment in order to transform it into purified water.

Absorption has a strong positive correlation with performance, because the system will be more efficient the higher the percentage of water uptake in the environment. Similarly, filter adhesion has a strong positive correlation with durability, as the system is intended to be maintained for proper operation.

Supply has a strong positive correlation with both humidity control and speed control, as these two parameters are indispensable for the optimal functioning of the prototype.

However, stability and collapsibility have a strong negative correlation, as it is not possible for the prototype to be collapsible and stable at the same time, but it can be stable and light.

Thermal conductivity has a strong negative correlation with supply, the materials to be used with the design also have a negative correlation. The fact that it is collapsible will not necessarily indicate optimal performance, so these two characteristics have a strong negative correlation.

Performance and firmness have a strong negative correlation, however, firmness has a positive relationship with storage, because the water that will be stored in the container must be kept in its original position, in order to avoid overflow or contamination of the water. Therefore hardness and storage have a positive correlation.

Hardness has a strong negative correlation with visibility, while design has a strong positive correlation with visibility, the process is intended to be sufficiently visible to detect any anomalies that may occur, as well as to change the filtrate when necessary.

Optimal performance has a strong positive correlation with visibility, because the more visible the process is, the easier it is to detect faults in the process.

Expansion has a strong negative correlation with moisture control, while expansion has a positive correlation with durability. It should be noted that the environment in which the system will be operating will have a high percentage of humidity, so it is important to choose materials capable of functioning normally under these conditions.

To make the correlation matrix between customer requirements and quality characteristics, the following symbology was used:

Θ Indicates strong correlation, the value of which is 9.

O Indicates moderate correlation, the value of which is 3

▲ Indicates poor correlation, the value of which is 1

The columns that obtained high relative values were:

Column 1 with a relative value of 8.8 and column 10 with the same relative value.

Once the matrix analysis was completed, the competitive assessment was carried out the device has 3 strong competitors at present, which are shown below:

Competitor 1:

Eolewater is an innovation which allows water to be produced by extracting moisture from the air through a condensation process. (Parent, 2010) "Firstly, energy is extracted from the wind to generate electricity, and this is used to run an air conditioning system where moisture from the air is condensed to produce water." The machine sucks in air to deposit it in a system that cools a series of plates on which the moisture in the air condenses, forming water that flows into a collecting tank. "This is nothing more than a machine that produces rain," Parent pointed out.

Competitor 2:

Researchers from the University of Engineering and Technology (UTEC) in Lima collaborated with advertising agency Mayo Peru DraftFCB developed a panel that produces drinking water using air as a resource.

The panel is strategically located in the village of Bujama, an almost desert-like area south of Lima, where some residents have no access to drinking water. However, despite the harsh weather conditions, the air contains 98% humidity (UTEC, 2013).

The panel fulfils its traditional function as an advertising platform, while including the special task. Internally, the piece consists of five machines that convert the humidity in the air into water through the use of filters and a condenser. The water is stored in tanks at the top of the structure and, once filtered, flows through a pipe to the tap, to which everyone has access News Mundo [2013].

Competitor 3:

Fresh Water, on the other hand, is a technology that allows water to be obtained from the atmosphere by simply connecting it to a 220V electrical source, or through its own battery or solar source, without having the need to connect to a drinking water network, or rely on the logistics and supply of bottles or water trucks. What this system does is to recover the water suspended in the air through the phenomenon of condensation at ambient pressure. Subsequently and by employing filtering, purification and sterilisation stages, it provides purified water with high quality standards, (CENTER, 2014).

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Competitive analysis:

In conducting the competitive analysis, values from 0 to 5 were given where 0 indicated the worst and 5 the best. Customer requirements were evaluated and it was concluded that the biggest competitor to the system is Eolewater, because it meets most of the requirements that the customer requests in order to acquire a system capable of transforming moisture into purified water. However, this device is not within the reach of the strategic sector at which it is aimed. For the marketing phase, the sample size was determined, then a survey was designed and applied, with the purpose of knowing the market's opinion about a device capable of producing water through humidity, as well as the percentage of acceptance by consumers in order to determine the potential market and based on this to make the projection of the demand under the three scenarios. The subjects surveyed were rural families in the city of Altamira, Tamaulipas.

Sample size determination:

$$n = \frac{Z^2pqN}{e^2(N-1)+Z^2pq} \quad (1)$$

Ecuation 1. Sample size calculation

Where:

n= Sample size

Z= Confidence level (1.96)

p= Probability in favour (0.5)

q= Probability against (0.5)

N= Population (4000)

e= Estimation error (0.05).

Substituting obtained:

Substitution of the sample size calculation.

Subsequently, an estimation of the demand was made and surveys were applied, with the purpose of knowing the percentage of acceptance that the product in question would have.

Results

Figure 1 shows the application of the quality function deployment of the environmental humidity sensor device.

Some requirements have a greater impact which are: that it captures sufficient humidity (8.5%), that it is easy to use (8.1%), that it is light (6.5%) and finally that it is economical (6.2%). Therefore, the technical and operational characteristics to be considered for the design of the system will be: optimal performance, size, firmness, weight, filter adhesion and stability. On the other hand, in the competitor analysis it can be seen that the device has three strong competitors that meet most of the requirements of the customers. However, the only disadvantage is the inaccessible prices towards the targeted market segment.

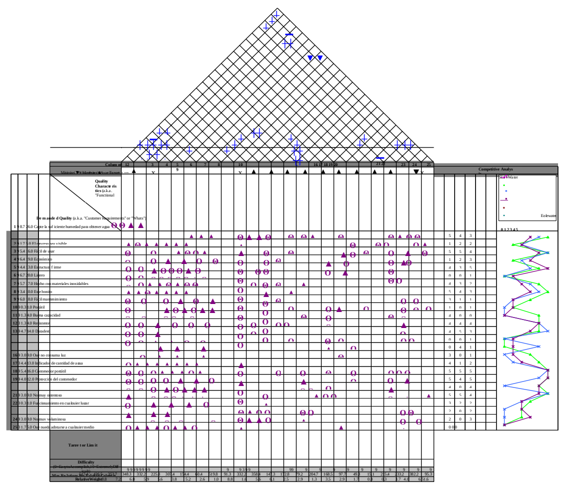

Figure 1 Deployment of the quality function of the system for the transformation of moisture into drinking water
Source: own production

Once the quality function deployment was performed and analysed, it was possible to carry out the implementation of the prototype taking into account the characteristics of the client and the operational techniques. This system will be able to collect the moisture present in the environment and transform it into purified water, benefiting families in rural communities, preventing diseases such as polio, hepatitis and other diseases caused by the ingestion of unhealthy water and poor sanitation conditions.

The following figure shows the proposed design considering the information obtained in the QFD, as well as the table of raw material costs.

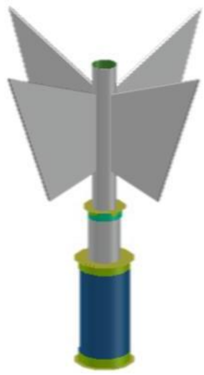

Figure 2 Prototype of the device
Source: the authors

Product	Quantity	Unit Cost	Total Cost
Shade netting	1.5 m	$ 118.90	$ 178.35
40mm PVC pipe	6 m	$ 10.80	$ 64.80
1" PVC pipe	0.5 m	$ 17.70	$ 8.85
10mm PVC pipe	1 m	$ 27.00	$ 27.00
3cm perforated PVC pipe	1 pza	$ 14.90	$ 14.90
3cm ball bearing	1 pza	$ 77.94	$ 77.94
3cm coupling	1 pza	$ 12.00	$ 12.00
Filter	1 pza	$ 15.00	$ 15.00
Funnel	3 pza	$ 16.00	$ 48.00
Acrylic sheet	4 pza	$ 74.90	$ 299.60
Hinge	2 pza	$ 3.00	$ 6.00
Total Cost			**$ 752.44**

Table 1 List of materials to make the prototype
Source: the authors

The results of the most relevant questions asked in the survey are presented below:

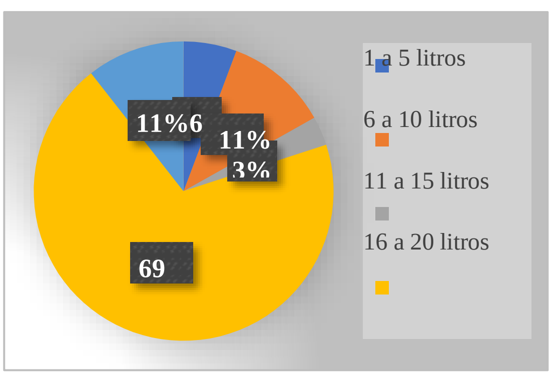

Figure 3 Quantity of purified water consumed
Source: the authors.

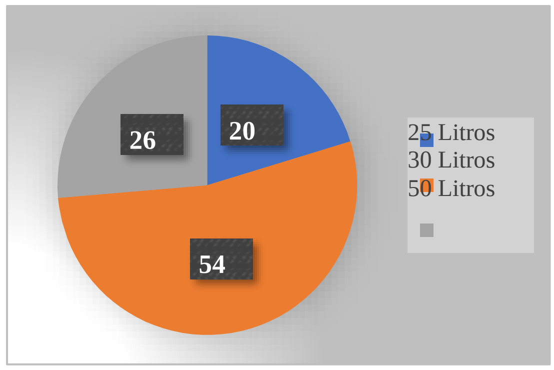

Figure 4 Litre capacity required
Source: the authors

Estimation and volume of demand.

Table 2 shows a sales projection of the ambient humidity sensor device.

Year	Madero	Tampico	Altamira	Total Anual
2023	201,251	240,755	298936	740,942
2024	201,362	246,515	297,846	745,723
2025	201,426	252,214	296,711	750,351
2026	201,512	257,944	295,598	755,054
2027	201,650	263,612	294,485	759,747
2028	201,732	269,374	293,372	764,478

Table 2 Estimated demand in the southern suburban area of Tamaulipas

In order to understand the various scenarios in which demand may occur, the following calculations were made.

Year	∑	% aceptación	% cobertura	Frec. De compra por semana	Penetración	Optimista	Escenarios Realista	Pesimista
		0.9	0.35	2	25%	80%	45%	30%
2023	740,942	666,847.80	233,396.73	466,793.46	116,698.37	93,358.69	52,514.26	35,009.51
2024	745,723	671,150.70	234,902.75	469,805.49	117,451.37	93,961.10	52,853.12	35235.41
2025	750,351	675,315.90	236,360.57	472,721.13	118,180.28	94,544.23	53,181.13	35,454.08
2026	755,054	679,548.60	237,842.01	475,684.02	118,921.01	95,136.80	53,514.45	35,676.30
2027	759,747	683,772.30	239,320.31	478,640.61	119,660.15	95,728.12	53,847.07	35,898.05
2028	764,478	688,030.20	240,810.57	481,621.14	120,405.29	96,324.23	54,182.38	36,121.59

Table 3 Demand scenarios

The estimated sales volumes up to the year 2023 under the three demand scenarios approach, it can be seen that the projected sales are attractive.

Acknowledgement

We thank the Tecnológico Nacional de México / Instituto Tecnológico de Ciudad Madero for the facilities to carry out this work.

Conclusions

Through the application of the tools it was possible to apply the marketing for the elaboration of the design to the project mentioned above, with the deployment of the quality function in addition to analysing the customer's expectations, allowed the analysis of the technical and operational characteristics that the system of transformation of moisture in purified water could offer to the communities lacking the vital liquid, because the cost of production will be reduced to the maximum the selling price will be minimal, and as a result more families in the state of Tamaulipas may have access to this device.

Once the market segmentation, the application of the surveys, the design and manufacture of the device had been carried out, it was proven that it is possible to produce up to 12 litres of water per day, under optimal conditions of parameters such as percentage of relative humidity and wind speed, satisfying the rural communities of the vital liquid.

It should be noted that among the design characteristics to be considered, it was taken into account that the client requires it to capture sufficient humidity, be easy to use, light and economical. With regard to the market study, it was found that there is a 90% acceptance rate and in the demand projection, carried out under three scenarios, the market viability can be appreciated as there are projections with a positive trend.

Although there are already devices capable of fulfilling this function, they are usually very expensive and are manufactured with sophisticated technology, generating a limitation for the acquisition of the same, it could be seen that with $752.44 it is possible to acquire the necessary inputs for the manufacture of the device.

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Effect of sowing speed on germination percentage in corn crop (*Zea mays*)

Efecto de la velocidad de siembra sobre el porcentaje de germinación en el cultivo de maíz (*Zea mays*)

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Abstract

The objective of the study was to evaluate the effect of three sowing speeds in commercial hybrid corn on the germination percentage in the Mezquital Valley, Hidalgo.
The P3270W hybrid was planted in the spring-summer cycle of 2023, with humidity at field capacity, at a density of 90,000 plants ha^{-1}. The germination percentage was evaluated at three sowing speeds: 3.5 km hr^{-1}, 5 km hr^{-1} and 7 km hr^{-1}. The experimental design was completely randomized with 81 m^2 per experimental unit, with three repetitions. Seed emergence data were collected at 5, 6 and 7 days after sowing. A completely randomized and Tukey (5%) design was used. A significant difference was observed in the germination percentage between the treatments. Sowing speed is decisive to obtain a higher germination percentage.

***Zea mays*, Germination, Sowing speed**

Resumen

El objetivo del estudio fue evaluar el efecto de tres velocidades se siembra en maíces híbridos comerciales sobre el porcentaje de germinación en el Valle del Mezquital, Hidalgo. El hibrido P3270W se sembró en el ciclo primavera verano de 2023, con humedad a capacidad de campo, a una densidad de 90,000 plantas ha^{-1}. Se evaluó el porcentaje de germinación en tres velocidades de siembra: 3.5 km hr^{-1}, 5 km hr^{-1} y 7 km hr^{-1}. El diseño experimental fue completamente al azar con 81 m^2 por unidad experimental, con tres repeticiones. La toma de datos de la emergencia de la semilla fue a los 5, 6 y 7 días después de la siembra. Se utilizó un diseño completamente al azar y Tukey (5%). Se observó diferencia significativa en el porcentaje de germinación entre los tratamientos. La velocidad de siembra es determinante para obtener un porcentaje de germinación más alto.

***Zea mays*, germinación, velocidad de siembra**

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Introduction

The Mezquital Valley in Hidalgo is characterised as a region largely dedicated to agriculture, which accounts for 59% of the state's total production. An essential characteristic of the Valley is its semi-arid climate and low rainfall, which makes it a region where agricultural activity would be limited. However, for more than a hundred years it has been receiving wastewater from the Metropolitan Zone of the Valley of Mexico (ZMVM), as a response to the serious flooding problems suffered by Mexico City. This led to a growth in agricultural activity in the Valley, mainly in the central sub-region, positioning it as the main agricultural producer in the State (García-Salazar, 2020).

Maize is one of the three main cereals produced in the world, along with wheat and rice, and it is also a cosmopolitan crop, which has allowed it to develop in an infinite number of climatic, soil, social and ecological conditions. There are many factors that influence maize productivity, starting from crop planning to harvesting. In this sense, rapid and uniform germination sets the first stage for achieving the potential yield at the end of the production cycle (Ramos, 2013) (Ángel Martínez Rengel, 2021). Maize is the most important agricultural crop in our country, from a food, industrial, political and social point of view (Government, 2020).

A quality seed contributes to greater productive varietal efficiency, as it is able to emerge quickly and uniformly, under different environmental conditions. Seed quality is a concept based on the assessment of different attributes (Kelly, 1988), which improve plant establishment in the field, including genetic, physiological, physical and sanitary quality (Basra, 1995; Copeland and McDonald, 1995). On the other hand, physical quality involves characteristics such as: moisture content, weight per volume and purity (Mendoza, 1996).

Faiguenbaum and Romero (1991) point out that physiological seed quality for different species is related to seed size. Other authors (Shieh and McDonald, 1982; Kelly, 1988) report that physiological quality does not depend on seed size.

Martinelli and Moreira de Carvalho (1999), when evaluating the influence of maize seed size in the field, found that large seeds germinated faster than small seeds, resulting in taller plants 25 days after sowing and, subsequently, ears with a higher number of grains per row and higher yield per unit area. These authors also mention that the type of hybrid causes different response to seed size variations.

Modern agriculture demands high quality seed, which is the main input in agriculture that must meet different attributes, including genetic, physiological, physical and sanitary quality. Germination and viability tests have been widely used in the evaluation of seed quality. It should be noted that physiological quality refers to intrinsic mechanisms of the seed that determine its germination capacity, the emergence and development of those structures essential to produce a normal seedling under favourable conditions. However, in recent years, emphasis has been given to the measurement of other parameters, such as vigour and the variables associated with this parameter (Josué Israel García-López, 2016).

In Mexico, different studies have been carried out in maize to quantify the effect of seed size on some seed quality characteristics, both agronomic and grain yield (Kurdikeri et al., 1998). Based on the above, the present research was carried out with the objective of knowing the effect of sowing speed on the germination percentage of maize seed.

Methodology to be developed

The study was carried out during the spring-summer cycle 2023, in the experimental field of the Polytechnic University of Francisco I Madero, Hidalgo, whose location is 20° 22' 40" N latitude, 99°08'81" W longitude, whose texture is classified as clayey crumb. The research was carried out in two phases: A laboratory phase and a field phase; in both a completely randomised experimental design was used. To guarantee the physiological quality in the laboratory, the "between paper" method (ISTA 1999) was used, which consisted of placing absorbent paper towels previously moistened with distilled water on a flat surface, on which 100 seeds were placed, distributed in ten columns by ten rows.

Once the seeds were properly placed, they were covered with more moistened towels and wrapped in the form of a roll, and then placed in an ICB® incubator at a constant temperature of 25 degrees Celsius. The seeds were monitored on the fourth, fifth, sixth and seventh day, until seedlings were observed with well-defined plumule and root, without malformations. Sowing was carried out on April 13, using the hybrid P3270W with a density of 90,000 plants per hectare deposited in the soil with a John Deere precision planter, previously tests were carried out to adjust the revolutions per minute to achieve the speeds corresponding to each treatment, then the seed was deposited at three sowing speeds: 7 km h-1, 5 km h-1 and 3.5 km h-1. To determine the emergence velocity index (EVI), the Maguire (1962) method was used, taking as emerged seedlings those that protrude from the substrate, this in five linear metres taken at random and in triplicate in each treatment, in the sampling, non-germinated grains and abnormal plants were counted.

Results

Table 1 shows the sowing efficiency according to the different sowing speeds, in which it is evident that the higher the sowing speed, the lower the number of emerged plants compared to the lower speed, this parameter is directly related to the sowing efficiency.

Speed (km/hr)	Actual density (Seeds / hectare)	Theoretical Density (seeds/hectare)	Sowing efficiency (%)
3.5	86130	90,000	95.7
5	82080	90000	91.2
7	81720	90000	90.8

Table 1 Sowing efficiency according to sowing speed

With regard to the emergence of seeds per square metre, it can be observed that the seedlings sown at a speed of 3.5 km hr-1, were those that presented the greatest number of emerged specimens and are statistically different, exceeding up to 12% more sprouted seeds with respect to those sown at a speed of 5 km hr-1. On the other hand, those sown at a speed of 7 km hr-1 are statistically equal to those sown at 5 km hr-1, however, sowing at a higher speed represents a loss of emergence of 0.82%. This factor undoubtedly affects the amount of product obtained per hectare (Figure 1).

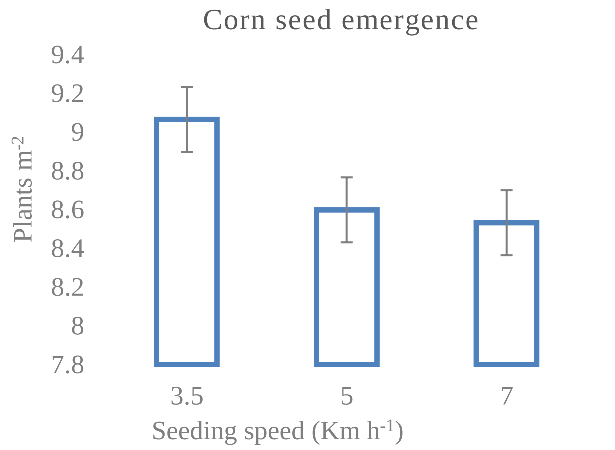

Figure 1 Figure 1.- Number of emerged seeds at different sowing speeds in maize

Figure 2, represents the germinated seeds in laboratory conditions, these values showed that it is a viable seed, because it reached 98 percent of the germination specified in the technical characteristics of the germplasm, allows to establish that the seeds will respond well to field conditions and will develop their potential vigour in in situ conditions.

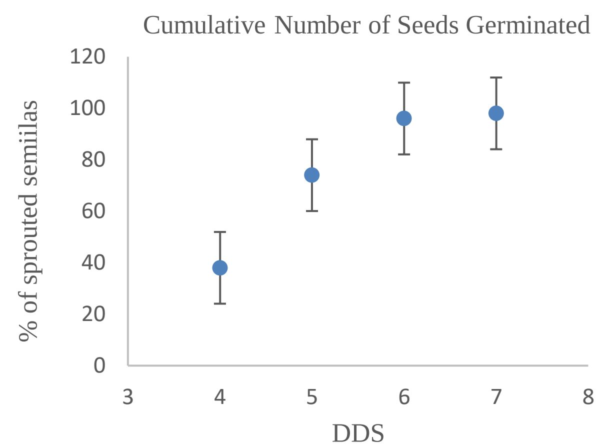

Figure 2

Acknowledgement

Special thanks to the company CORTEVA who kindly donated the test germplasm.

Conclusions

These results suggest that the sowing speed to obtain the greatest amount of emerged maize seeds should not exceed 3.5 km hr^{-1}, in order to guarantee the highest percentage obtained in the emergence of maize plants, because this apparently favours the adequate penetration of the seeds in the soil, implying that working with speeds higher than this value causes a considerable decrease in the amount of emerged germplasm, thus seeking to increase the yield of crops in the region.

Adequate regulation of the machinery avoids or minimises deficiencies in seed emergence, other intrinsic aspects are attributed to the operator's expertise, poor handling of the stubble on the ground, poorly applied irrigation.

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Article **Journal of Environmental Sciences and Natural Resources**
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Preliminary list of diurnal butterflies in the Vega de Metztitlán, Hidalgo

Listado preliminar de mariposas diurnas en la Vega de Metztitlán, Hidalgo

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Abstract

The present work was carried out in the municipality of Metztitlán within the area of the Biosphere Reserve "Barranca de Metztitlán", Hidalgo with the objective of contributing to the knowledge of diurnal butterflies of the region through a taxonomic list. The type of sampling was preferential using an entomological network mainly in crops of corn, alfalfa, sunflower and spaces with secondary vegetation with flowers. The collections were made in the period from March to Octuber 2023, the biological material was mounted with entomological pins and preserved in entomological boxes and the taxonomic identification was with specialized literature. 623 specimens were collected in the study area divided into six families, being Pieridae the most abundant with 219 individuals, Nymphalidae 210, Hesperiidae 97, Lycaenidae with 78, Papilionidae 14 and Riononididae with 5 individuals. Regarding temporal abundance, July obtained 23.1% of the total number of registered individuals. Regarding diversity, 93 Lepidoptera were identified at the species level belonging to 67 genera, the most abundant genus was *Anartia* with 40 specimens and 18 genera only presented 1 specimen. The most abundant species was Anaea aidea with 12 specimens. The most abundant species were *Anartia fatima*, *Danaus gilippus* and *Melete lycimia* with 28 specimens each.

Diversity, Rhopalocera, Biosfere Reserve

Resumen

The present work was carried out in the municipality of Metztitlán within the area of the Biosphere Reserve "Barranca de Metztitlán", Hidalgo with the objective of contributing to the knowledge of diurnal butterflies of the region through a taxonomic list. The type of sampling was preferential using an entomological network mainly in crops of corn, alfalfa, sunflower and spaces with secondary vegetation with flowers. The collections were made in the period from March to Octuber 2023, the biological material was mounted with entomological pins and preserved in entomological boxes and the taxonomic identification was with specialized literature. 623 specimens were collected in the study area divided into six families, being Pieridae the most abundant with 219 individuals, Nymphalidae 210, Hesperiidae 97, Lycaenidae with 78, Papilionidae 14 and Riononididae with 5 individuals. Regarding temporal abundance, July obtained 23.1% of the total number of registered individuals. Regarding diversity, 93 Lepidoptera were identified at the species level belonging to 67 genera, the most abundant genus was *Anartia* with 40 specimens and 18 genera only presented 1 specimen. The most abundant species was Anaea aidea with 12 specimens. The most abundant species were *Anartia fatima*, *Danaus gilippus* and *Melete lycimia* with 28 specimens each.

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Introduction

Lepidoptera are the third order of insects with the most described species, after the orders Coleoptera and Diptera (Zhang, 2011). They are also the best studied group of insects. They are also interesting as indicators of ecosystem conservation quality and climate change (Van Swaay et al., 2012). It is the insect order with the most species considered to be of economic importance. There are thirteen superfamilies with pest species, including the Gelechioidea, Noctuoidea, Ponomeutoidea, Tortricoidea and Pyraloidea (Selfa and Anento, 1997). The species richness of Lepidoptera differs according to authors, Pogue (2009) proposes a total of 155,181 species. Currently, 157,424 species are estimated to have been described in the world (Van Nieukerken et al., 2011). In Mexico, the panorama is changing in the same way, although to a lesser extent. In 2002, there was a total record of 14,383 described species and around 22,440 estimated species (Heppner, 2002).

Currently, 23,750 species of Lepidoptera are estimated, with 14,507 described and documented (Llorente-Bousquets et al., 2014). Pollination is the phenomenon by which pollen grains are transferred from the anthers to the stigmas, making sexual reproduction of plants possible and thus ensuring their permanence. It is therefore a fundamental process for the reproduction of angiosperm plants. This transport is often wind-driven; sometimes water is the vehicle used. But most flowering plants need the collaboration of other living beings which, in exchange for some kind of reward (usually in the form of food), facilitate the arrival of the pollen grains at their destination. Exact data are not available, but recent studies estimate that 87.5 % of angiosperm plants (about 308,000 species) depend on animals for pollination and viable seed production, with a higher percentage in tropical areas (94 %) than in temperate zones (78 %) (Ollerton et al., 2011). In addition, 75 % of plant species cultivated by humans are pollinated by insects (Klein et al., 2007). Pollinators (the vast majority of which are insects) therefore play a crucial role in terrestrial biodiversity. A study published in 2009 estimates that the global economic value of pollinating insects in 2005 was 153 billion euros, representing 9.5% of the value of global agricultural production used for human food that year (Gallai and Vaissière et al., 2009).

Lepidoptera are important pollinating agents as they feed on flowers and carry pollen from one flower to another, contributing to fruit and seed formation and thus to plant reproduction. This paper reports the abundance and taxonomic diversity, as well as the temporal distribution during eight months of diurnal butterflies present in the Vega de Metztitlán area, Hidalgo, Mexico.

Methodology

The study was carried out in the municipality of Metztitlán within the area of the Biosphere Reserve "Barranca de Metztitlán", which is located in the centre of the territory of Hidalgo, 94 km north of the state capital Pachuca. The study area has mainly xerophytic scrub vegetation, with a predominant BS0hw climate, dry and semi-warm, with rainfall in summer. The average annual rainfall does not exceed 500 mm, reaching 600 and up to 700 mm in the higher altitude areas, and a temperature of 18 to 22°C (SPP, 1992).

The choice of sites consisted of green sites within the cultivated area of the Vega de Metztitlán and remnants of xerophytic scrubland near the Biosphere Reserve. The type of sampling was preferential, collections were made during the months of March to October 2023 once a week between 10:00 and 16:00 hours and in sunny conditions when the temperature was above 20ºC (Pollard, 1977). Adult butterflies were captured by the direct method using an entomological net, each butterfly was sacrificed by squeezing the abdomen to destroy the internal organs and stored in a plastic container with the collection data. The collected lepidoptera were transported to the Chemistry laboratory of the Unidad Académica Metztitlán, Universidad Politécnica de Francisco I. Madero, where the following activities were carried out:

Mounting and conservation. The specimens were mounted with entomological pins and deposited in wooden entomological boxes 40 x 60 cm wide and 10 cm high for their preservation and maintenance. The following data were recorded for each individual: Place of collection, family, scientific name and date of collection.

For taxonomic identification we used keys and specialised catalogues from Jeffrey Glassberg 2017: A Swift Guide to the Butterflies of Mexico and Central America second edition and the interactive list of the website https://www.butterfliesofamerica.com/intro.htm.

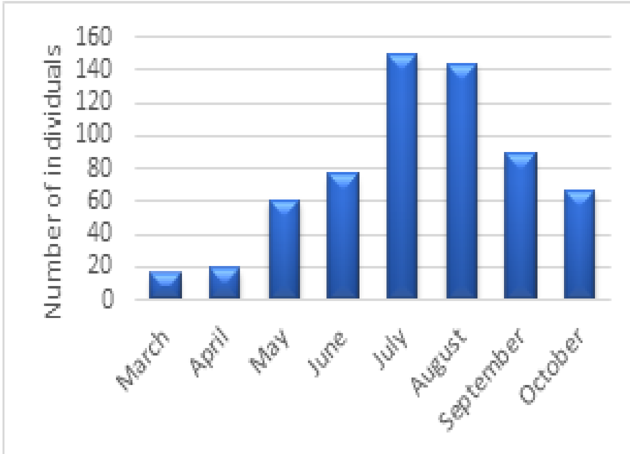
Results

The abundance of Lepidoptera found in the study area totals 623 specimens, and they are represented in six families, with Pieridae being the most abundant with 219 individuals, Nymphalidae with 210, Hesperidae 97, Lycaenidae 78, Papilionidae 14 and Rionididae with 5 individuals. In relation to subfamilies, 19 subfamilies were found in this study, with the Nymphalidae family being the largest with eight subfamilies: Apaturinae, Biblidinae, Charaxinae, Cyrestinae, Danainae, Heliiconinae, Libytheinae and Nymphalinae. Secondly, the family Hesperiidae had five subfamilies: Eudaminae, Hesperiinae, Heteropterinae, Pyrginae and Pyrrhopyginae. The family Pieridae recorded two subfamilies Coliadinae and Pierinae, Lycaenide had two subfamilies Theclinae and Polyommatinae, the family Papilionidae only recorded the subfamily Papilioninae as well as Riodinidae with the subfamily Riodininae (Table 1).).

Subfamily	Genres	Species
Nymphalinae	6	8
Heliconiinae	6	7
Danainae	1	3
Apaturinae	1	1
Charaxinae	1	1
Cyrestinae	1	1
Libytheinae	1	1
Biblidinae	5	5
Eudaminae	5	6
Pyrginae	7	8
Heteropterinae	1	3
Hesperiinae	5	5
Pyrrhopyginae	1	1
Coliadinae	8	14
Pierinae	5	5
Theclinae	7	11
Polyommatinae	3	5
Papilioninae	2	7
Riodininae	1	1
Totales	**67**	**93**

Table 1 Number of butterfly species per subfamily

In relation to temporal variations, specimens were collected during eight months from March to October 2023. The most abundant month was July with 24% of the total number of individuals recorded, August had 23.1%, a similar abundance to July, while March had the lowest abundance with 2.6% of the total number of individuals (Graphic 1).



Graphic 1 Abundance of individuals by month during 2023

The analysis of genera by family showed that Nymphalidae was represented by 22, followed by Hesperiidae with 19, Pieridae with 13, Lycaenidae with 10, Papilionidae with 2 and finally Riodinidae with 1. The family with the highest specific richness was Nymphalidae with 27 species, followed by Hesperiidae with 23, Pieridae with 19, Lycaenidae with 16, Papilionidae with 7 and finally Riodinidae with 1 genus. In terms of diversity, 93 species were identified, 91 at the specific level and two specimens at the morphospecies level, divided into 67 genera.

Species diversity

The most abundant genera were Anartia with 40 specimens and Danaus with 38 and 18 genera with only one specimen. At species level, the most abundant were *Anartia fatima*, *Danaus gilippus* and *Melete lycimia*, all with 28 specimens, representing 13.5% of the total abundance. On the other hand, 32 species were present with only one specimen in the entire sampling (Table 2).

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Family	Species	Autor
Nymphalidae	*Anartia fatima*	(Fabricius, 1793)
Nymphalidae	*Anartia jatrophae*	(Linnaeus, 1763)
Nymphalidae	*Chlosyne lacinia*	(Geyer, 1837)
Nymphalidae	*Phyciodes pallescens*	Ferder, 1869
Nymphalidae	*Phyciodes texana*	(W. H. Edwards, 1863)
Nymphalidae	*Junonia genoveva*	(Cramer, [1780])
Nymphalidae	*Nymphalis antiopa*	Linnaeus, 1758
Nymphalidae	*Texola elada*	(Ewitson, 1868)
Nymphalidae	*Agraulis vanillae*	(Linnaeus, 1758)
Nymphalidae	*Dione moneta*	(Cramer, [1779])
Nymphalidae	*Dryas iulia*	(Fabricius, 1775)
Nymphalidae	*Dryadula phaetusa*	(Linnaeus, 1758)
Nymphalidae	*Heliconius charithonia*	(Linnaeus, 1767)
Nymphalidae	*Euptoieta claudia*	(Cramer, 1775)
Nymphalidae	*Euptoieta hegesia*	(Cramer, 1779)
Nymphalidae	*Danaus plexippus*	Linnaeus, 1758
Nymphalidae	*Danaus gilippus*	(Cramer, [1775])
Nymphalidae	*Danaus eresmus*	(Cramer, [1777])
Nymphalidae	*Doxopa laure*	Drury, 1773
Nymphalidae	*Anaea aidea*	(Guérin-Méneville, 1844)
Nymphalidae	*Marpesia petreus*	(Cramer, 1776)
Nymphalidae	*Libytheana carinenta*	(Cramer, 1777)
Nymphalidae	*Biblis hyperia*	(Cramer, 1779)
Nymphalidae	*Eunica monima*	(Stoll, 1872)
Nymphalidae	*Hamadryas guatemalena*	Bates, 1864
Nymphalidae	*Myscelia cyaniris*	Doubleday, [1848]
Nymphalidae	*Mestra amymone*	(Ménétriés, 1857)
Hesperiidae	*Codatractus melon*	(Godman y Salvin, 1893)
Hesperiidae	*Urbanus proteus*	(Linnaeus, 1758)
Hesperiidae	*Urbanus procne*	(Plötz, 1880)
Hesperiidae	*Epargyreus aspina*	Evans, 1952
Hesperiidae	*Chioides catillus*	(Cramer, 1780)
Hesperiidae	*Phocides polybius*	Fabricius, 1793
Hesperiidae	*Pyrgus philetas*	Edwards, 1881
Hesperiidae	*Pyrgus communis*	(Grote, 1872)
Hesperiidae	*Systasea pulverulenta*	(Felder, 1869)
Hesperiidae	*Heliopetes laviana*	Felder 1869
Hesperiidae	*Nisoniades godma*	Hübner, 1819
Hesperiidae	*Cabares potrillo*	(Lucas, 1857)
Hesperiidae	*Pachyneura licisca*	(Plötz, 1882)
Hesperiidae	*Pholisora catallus*	(Fabricio, 1793)
Hesperiidae	*Piruna microsticta*	(Godman, 1900)
Hesperiidae	*Piruna* sp	Evans, 1955
Hesperiidae	*Piruna gyrans*	(Plötz, 1884)
Hesperiidae	*Hylephyla phyleus*	(Drury, 1773)
Hesperiidae	*Cobalopsis nero*	(Herrich-Schäffer, 1869)
Hesperiidae	*Copaeodes minimus*	(Edwards, 1870)
Hesperiidae	*Atalopedes campestris*	Boisduval, 1852
Hesperiidae	*Oarisma edwardsii*	(Barnes, 1897)
Hesperiidae	*Pyrrhopyge chalybea*	Scudder, 1872
Pieridae	*Eurema protepia*	(Fabricio, 1775)
Pieridae	*Eurema nicippe*	(Cramer, 1779)
Pieridae	*Eurema mexicana*	(Boisduval, 1836)
Pieridae	*Eurema daira*	(Godart, [1819])
Pieridae	*Phoebis philea*	(Linneo, 1763)
Pieridae	*Phoebis sennae*	(Linnaeus, 1758)
Pieridae	*Phoebis orgarithe*	(Boisduval, [1836])
Pieridae	*Anteus clorinde*	Godart, 1824
Pieridae	*Anteus maerula*	(Fabricius, 1775)
Pieridae	*Nathalis iole*	(Boisduval, 1836)
Pieridae	*Aphrissa statira*	(Cramer, 1777)
Pieridae	*Colias eurytheme*	(Boisduval, 1852)
Pieridae	*Pyrisitia nise*	(Cramer, [1775])
Pieridae	*Zerene cesonia*	(Stoll, 1790)
Pieridae	*Ascia monuste*	(Linnaeus, 1764)
Pieidae	*Leptophobia aripa*	(Boisduval, 1836)
Pieridae	*Melete lycimnia*	(Cramer, 1777)
Pieridae	*Pontia protodice*	(Boisduval y Leconte, 1830)
Pieridae	*Castasticta nimbice*	(Boisduval, 1836)
Lycaenidae	*Arawacus jada*	(Hewitson, 1867)
Lycaenidae	*Atlides gaumeri*	(Godman 1901)
Lycaenidae	*Atlides halesus*	(Cramer, 1777)
Lycaenidae	*Eumaeus childrenae*	(Gray, 1832)
Lycaenidae	*Parrhasius moctezuma*	(Clench, 1971)
Lycaenidae	*Parrhasius polibetes*	(Stoll, [1781])
Lycaenidae	*Rekoa marius*	(Lucas, 1857)
Lycaenidae	*Panthiades bathildis*	(C. & R. Felder, 1865)
Lycaenidae	*Strymon albata*	(C. & R. Felder, 1865)
Lycaenidae	*Strymon istapa*	(Reakirt, [1867])
Lycaenidae	*Strymon melinus*	Hübner, 1818
Lycaenidae	*Everes comyntas*	(Godart, 1824)
Lycaenidae	*Hemiargus ceraunus*	(Fabricio, 1793)
Lycaenidae	*Hemiargus isola*	Reakirt, 1867)
Lycaenidae	*Leptotes cassius*	(Cramer, 1775)
Lycaenidae	*Leptotes marina*	(Reakirt, 1868)
Papilionidae	*Papilio anchisiades*	Esper, 1778
Papilionidae	*Papilio pharnaces*	Doubleday, 1846
Papilionidae	*Papilio polyxenes*	Fabricio, 1775
Papilionidae	*Papilio garamas*	Geyer, 1829
Papilionidae	*Papilio thoas*	Linnaeus, 1771
Papilionidae	*Eurytides epidaus*	(Doubleday,1846)
Papilionidae	*Eurytides philolaus*	(Boisduval, 1836)
Riodinidae	*Calephelis* sp	Grote y Robinson, 1872

Table 2 Species recorded for the area of Vega de Metztitlán, Hidalgo

The family that represented a greater number of species captured was Nymphalidae, these results coincide with Hernández, 2020 where he conducted a study on the diversity of Lepidoptera in the northeast of the state of Hidalgo where he found that the family Nymphalidae was the most diverse, another study by Pérez, 2017 in a gradient of urbanization in the metropolitan area of Pachuca also presents the family Nymphalidae with greater diversity similar to this work.

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Undoubtedly, abiotic and biotic factors have a direct and indirect impact on the abundance of species, as seen in this study, in March there are very few individuals recorded as it is still cold for the study area, and as time progresses it can be seen how the abundance and diversity of species are increasing, This coincides with the onset of spring and summer, when the flowering of plant species begins, which provides food for the butterflies. The rainy season also marks the growth of new foliage, favouring the feeding of butterfly larvae and their development, which completes their life cycle at this time. With the arrival of autumn and low temperatures, the absence of green leaves and succulents causes the abundance of Lepidoptera to begin to decline.

The results of the sampling effort in this work indicate that a large proportion of the species present in the different sites collected in the Vega de Metztitlan area were recorded, taking into account that this region is an area of agricultural activities, where a large amount of agrochemicals are applied that could reduce the presence of butterflies. However, more than 90 species of butterflies were found, although the direct collection technique used was effective, it is necessary to make a greater sampling effort and use other complementary techniques such as, for example, Van Someren-Rydon traps (baited lures) to have an even greater representativeness, which would undoubtedly record more than 100 species for the area.

Conclusions

Rhopalocera are found throughout the year in the Vega de Metztitlán, Hidalgo, and in this work 623 individuals were collected from March to October 2023. They are represented in 6 families, 19 subfamilies, 67 genera and 93 species. The family with the highest abundance was Pieridae (35.2%) and the family with the highest species richness was Nymphalidae (29%) and number of genera (22).

The most abundant genus was *Anartia* (40 individuals) and 18 genera had only one specimen.

At species level, the most abundant butterflies were *Anartia fatima, Danaus gilippus and Melete lycimia* with 28 specimens each. On the other hand, 32 species were present with only one specimen in the entire sampling.

The most abundant month was September, capturing 50% of the individuals in this month. Taxonomic diversity was not reflected in the composition of the landscape, as species were found in the cultivated areas of the Vega de Metztitlán as well as in the conserved areas of the Biosphere Reserve.

It is recommended to make a greater sampling effort by implementing other techniques to know the species present in the study area, since the population dynamics of the species change in time-space.

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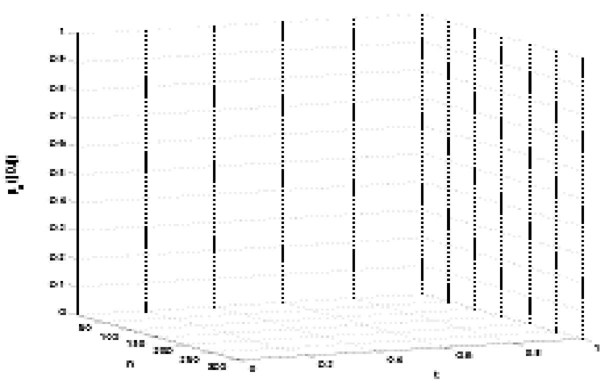

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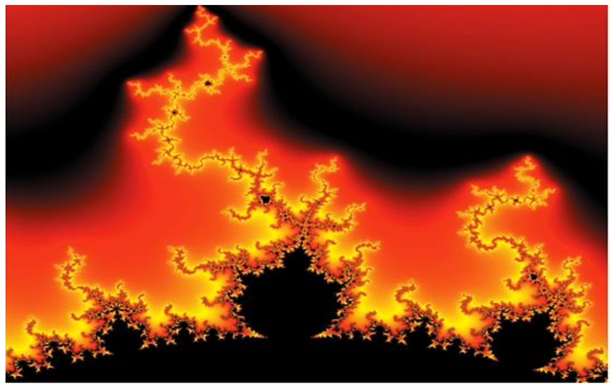

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