Article

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Reviewing the Mesquite (*Prosopis laevigata*) Potential to Strengthen the Sustainability of the Mexican Food System

Revisando el Potencial del Mezquite (*Prosopis laevigata*) para Fortalecer la Sustentabilidad del Sistema Alimentario Mexicano

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Abastract

The stability of the planetary system and the protection of natural resources for future generations are the most important challenges for humanity. Given the food system impact on planetary boundaries, to develop strategies and technologies to reach sustainability has a great relevance. A restructuration of the world food system elements including resilient species, in a new framework different to the current agricultural practices, is a suitable option. In this context the mesquite (*Prosopis laevigata*), a tree with nitrogen fixing capacity and adapted to dryland, is described as a species that, with its outstanding biological and nutritional properties, is a strategic element to reach a healthier and sustainable food system.

Legume, Protein, Sugars

Resumen

La estabilidad del sistema planetario actual y el resguardo de los recursos naturales para las generaciones futuras son los retos más importantes a los que se enfrenta la humanidad. Dado el impacto que el sistema alimentario representa para la estabilidad de los limites planetarios, el desarrollo de estrategias y tecnologías que permitan alcanzar la sustentabilidad es de la mayor relevancia. La reestructuración de los elementos del sistema alimentario mundial incorporando especies de mayor resiliencia en esquemas diferentes a las actuales prácticas agrícolas es una opción viable. En este contexto se describe al mezquite (*Prosopis laevigata*), un árbol con la capacidad de fijar nitrógeno y adaptado al semidesierto, como una especie que por sus características biológicas y nutrimentales es un elemento estratégico en la búsqueda de un sistema alimentario más sano y sustentable.

Leguminosa, Proteína, Azúcares

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The Food System

Despite efforts and plans to colonise the moon or Mars, the earth is currently the only source of resources for the more than eight billion humans that inhabit it (Perchonok *et al*., 2012). The water, energy, materials and food needed for today's societies can only be obtained from this planet, whose resources are finite. The impact that human societies exert by demanding resources and generating waste has exceeded the safe limits for the continuation of human activities on earth as we know it.

Of the nine established planetary boundaries, humanity has irreversibly damaged biodiversity, climate change and the nitrogen cycle (Rockström *et al*., 2023). If the current scenario is a major challenge, meeting the needs of more than nine billion people in 2050 is an even greater challenge. The way humanity consumes resources and produces waste must be reconsidered and restructured, with the aim of achieving a balance with the environment and not compromising the future of the next generations.

Food production, which today's society demands, is one of the most responsible elements of global stress. The current food system uses 50% of the habitable surface, consumes 70% of water, produces 30% of greenhouse gases, is mainly responsible for land use change, deforestation, loss of biodiversity, soil degradation and pollution of the atmosphere and water (Crippa *et al*. 2021). On the other hand, the structure of the current food system maintains a condition of malnutrition for a large part of the population, which allows the prevalence of malnutrition in infants and women of reproductive age mainly, while at the same time allowing high rates of overweight and obesity in children and adults (Global Nutrition Report, 2021).

In Mexico, 15 % of women of reproductive age suffer from some degree of anaemia, only 28 % of children between 0 and 5 months are exclusively breastfed, undernutrition in children under 5 is 14 %, overweight in children under 5 is more than 6 %, 36 % of children between 5 and 19 are overweight and 15 % obese, more than 30 % of adults are obese and more than 60 % are overweight (Global Nutrition Report, 2021).

The structure of the current food system, which affects the environment and generates conditions of malnutrition, has been described as a syndemic, referring to the global prevalence of undernutrition and obesity, associated with climate change and integrating two of the main challenges facing modern societies, human health and planetary health (Swinburg *et al*., 2019).

While the food system has a direct link to the concept of syndemia, described above, it is made up of different elements and each of these elements has a greater or lesser impact on human health or planetary health. Considering the current production and consumption of 15 food groups (chicken, dairy, eggs, fish, fruits, legumes, nuts, olive oil, potatoes, processed red meat, refined cereals, sugary drinks, red meat, vegetables and whole grains) and their impact on health (type 2 diabetes, embolism, coronary heart disease, colon cancer and mortality) and the environment (greenhouse gas emissions, land use, water use, acidification and eutrophication) it is possible to identify the implications of each food group and the differences and similarities between them. (Clarka, Springmanna, Hilld & Tilmane, 2019).

This analysis shows that the fruit and vegetable group has a low impact on both human health and planetary health, while the legume group has a low impact on both aspects except for land use, on which it has a medium impact, nuts have a medium impact on acidification and a high impact on water use, whole grains have a low impact on human health, but on planetary health they have a medium impact on water use, land use and eutrophication, potatoes have a low impact on planetary health.

But on human health they have a medium impact on colon cancer and diabetes, olive oil has a low impact on all indicators except water use, refined grains have a medium impact on mortality and coronary heart disease and on planetary health it has a medium impact on water use, land use and eutrophication, sugary drinks have a high impact on human health, specifically, they have a medium impact on mortality and stroke, but they show a high impact on coronary heart disease, but show a high impact on coronary heart disease, colon cancer and diabetes.

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While in planetary health they only have a medium impact on eutrophication, fish has a low impact on human health, but in planetary health it has a medium impact on water use and acidification and a high impact on greenhouse gas emissions and eutrophication, eggs have a medium impact on mortality, colon cancer and diabetes and on greenhouse gas emissions, acidification and eutrophication, dairy has a low impact on human health, but in planetary health it has a medium impact on water use and acidification and a high impact on greenhouse gas emissions and eutrophication, dairy has a low impact on human health, but on planetary health they have a medium impact on greenhouse gas emissions, water use, land use, acidification and eutrophication, chicken maintains the same profile as described for dairy, red meat has a medium impact on the five human health indicators and a high impact on the five planetary health indicators, and finally processed red meat has a high impact on the five human health and planetary health indicators (Clarka, Springmanna, Hilld & Tilmane, 2019).

From the above it should be noted that the production and consumption of food groups with low impact on human health, coincides with that they are the food groups that have a low impact on planetary health, so the food system should be integrated from this food group as a priority (fruits, vegetables, legumes and whole grains) and in turn the production and consumption of food groups with high impact on human health, coincides with these being the food groups that have a high impact on planetary health, so the food system should be integrated from this food group in lower proportion (animal products, specifically, red meat, processed red meat) (Clarka, Springmanna, Hilld & Tilmane, 2019).

It is clear that not all food groups have the same impact on human health and planetary health, and that foods of animal origin have the greatest impact on planetary health; specifically, these food groups use 80% of the arable land area and produce 70% of the greenhouse gases from the food system, but account for only 18% of the calories consumed in the human diet (Clarka, Springmanna, Hilld & Tilmane, 2019; Swinburg *et al*. 2019).

While animal-based food groups have a high impact on planetary health, these foods represent the main source of good quality protein in the human diet, so a strategy aimed at limiting or reducing their production and consumption must consider alternative sources that will substitute for this source of protein, which does not result in high impacts on human or planetary health (Climateworks Foundation, 2021). Although new technologies such as precision fermentation, cellular agriculture or the adoption of insect protein have been identified as possible useful tools for obtaining alternative protein, plant protein is the main source of protein for the human diet that is most viable in the short term (Climateworks Foundation, 2021), so the search for and adoption of crops that offer advantages in the production of good quality protein that can be integrated into the global food system is a fundamental part of achieving a sustainable food system, friendly to human health and planetary health.

Considering the food groups that give structure to the diets maintained in the context of the current food system and generating a change that favours human health and planetary health seems a viable strategy to achieve a sustainable food system. In response to this trend, a global sustainable diet has been proposed (Willett, 2019), which specifically calls for reducing the consumption of most animal-based foods by half and increasing the consumption of plant-based foods by more than 100 percent, with particular emphasis on increasing the consumption of legumes as a major source of protein (Willett, 2019).

Legumes, due to their ability to fix atmospheric nitrogen and accumulate it in the form of protein reserves in their seeds and to demand less water during their production, are a food group whose production and consumption are strategic in reducing the impact of the food system on planetary health and also on human health, given their important contribution of protein, complex carbohydrates, minerals, fibre and active compounds (Semba, Ramsing, Rahman, Kraemer & Bloem, 2021). Given the important role that plant protein sources play in the restructuring of the current food system, initiatives have been undertaken with the aim of describing new raw materials whose agronomic, nutritional and gastronomic characteristics can be incorporated into a sustainable food system.

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The already well-known soybean, pea, canola, fava bean, lentil, bean, peanut, quinoa, sorghum, sunflower seeds are being integrated to a greater extent into the development of high-demand food products and lesser-known raw materials such as chia, quinoa, lupine, flaxseed, hemp, pumpkin seed, sesame and mesquite are being valued with outstanding results (Good Food Institute, 2021). The restructuring of the current food system to one that is more sustainable and less dependent on animal protein will not depend on monoculture and will be made possible by the integration of multiple protein sources, including plant protein, whose production is closely linked to the context of countries and regions.

The Mesquite

In the pre-Hispanic cosmovision, reflected in different codices (Borgia, Tudela, Fejérváry-Mayer), the existence of a cosmic axis supported by four sacred trees is proposed, one of these trees is a precious mesquite (Quetzalmizquitl), on which an eagle perches (López-Austin, 2018). For the hunter-gatherer, immigrant, semi-nomadic groups originating from the north that arrived in the Basin of Mexico (also pejoratively called Chichimecas), the mesquite was a fundamental part of their subsistence in the semi-desert, their diet was mainly made up of mesquite pods, nopales, flowers, biznagas and tunas that they complemented with bushmeat that they hunted thanks to their great skill with the bow made of mesquite root (Valdés, 2017).

The relevance of mesquite for the inhabitants of the Mexican semi-desert was such that it was included in the name of important regions that were later modified, such as San Luis de Mezquitique, whose name was changed to San Luis Potosí (Durán-Sandoval, 2015). There is evidence of the use of its pod in the elaboration of everyday products, in the human diet and for livestock; its use in the elaboration of mesquite wine, a distilled alcoholic beverage made from mesquite pods, prohibited in 1785 by the Spanish crown, stands out (de Orozco Y Berra, 1855). The mesquite is a tree that has accompanied the human societies that inhabit the semi-desert, particularly those that, due to the inhospitable nature of their territories, have based their development on the home and gathering, for which agriculture is not viable due to the low availability of water and the low fertility of the soil.

The genus *Prosopis* is a group of tree species of the family Fabaceae, also known as mesquite, which includes 44 species distributed mainly in arid and semi-arid regions of Asia, Africa and America. (Felker, Takeoka & Dao, 2013). Species of the genus Prosopis were an important crop for indigenous peoples before the arrival of the Spanish (Felker, Takeoka & Dao, 2013). The mesquite complex is firmly established on more than 3.5 million hectares in north-central Mexico and includes the following native species, mainly: P. *glandulosa, P. juliflora, P. velutina, P. pubescens, P. reptans, P. articulata, P. tamaulipana, P. palmeri* and *P. laevigata* (Rodríguez-Sauceda, 2014). Mesquite, being a legume, has the capacity to fix atmospheric nitrogen; it can fix up to 50 kg of nitrogen per hectare per year. Considering that nitrogen, unlike calcium, phosphorus and potassium, does not exist in mineral form in the soil, its fixation from atmospheric nitrogen is a determining factor in carbon fixation and soil fertility, even more so than water availability (Puppo & Felker, 2021).

Nitrogen fixation of mesquite in the semi-desert allows subsequent carbon sequestration and activation of the microbiome, reduces soil density, improves the condition of the rhizosphere, increases water infiltration, increases the cation exchange capacity of the soil and reduces nutrient leaching (Puppo & Felker, 2021). For every kg of nitrogen fixed by a mesquite tree, 12 kg of carbon are sequestered. Considering the extent of the semi-arid regions of the world, which represent 25% of the land surface and 35% of the territory of the Mexican Republic, the semi-desert represents an opportunity for carbon capture and storage if its biodiversity is properly managed (Puppo & Felker 2021; Díaz-Padilla, 2011).

The environmental services offered by mesquite are very important, but its use as a source of food and materials seems to be even greater. In this sense, it is important to highlight that 35 % of the territory of the Mexican Republic maintains semi-desert conditions, and that these regions are home to 33 % of the national population (Díaz-Padilla, 2011), a population that demands food and services and for whom mesquite can be a real opportunity for development, which is why mesquite was once considered a sacred tree, but is nowadays more of a forgotten resource.

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In Mexico, the genus *Prosopis* or mesquite can be found in most of the states of the republic, with a specific distribution, where wild populations of *P. odorata* can be found in Sonora, Chihuahua, Tamaulipas and Baja California; *P. glandulosa* in Coahuila, Nuevo León and Tamaulipas; *P. velutina* in Sonora*; P. articulata* in Baja California and Sonora. articulata in Baja California and Sonora; *P. tamaulipana* in Nuevo León, San Luis Potosí, Tamaulipas and Veracruz; *P. laevigata* in Aguas Calientes, Chiapas, Durango, State of Mexico, Guanajuato, Guerrero, Hidalgo, Jalisco, Michoacán, Morelos, Nuevo León, Oaxaca, Puebla, Querétaro, San Luis Potosí, Tamaulipas and Zacatecas; and *P. juliflora* in Yucatán. The most widely distributed species in Mexico is *P. laevigata*, which can be found in the arid and semi-arid regions of 17 states in northern and central Mexico (Palacios, 2006).

The species Prosopis laevigata, which we will refer to as mesquite, is a tree adapted to semi-arid regions that is between 4 and 12 metres tall, but can reach up to 15 metres or be a 3-metre shrub depending on the conditions of the environment in which it grows (Palacios, 2006). Mesquite can develop a deep root that extracts water from the subsoil and allows the development of a microclimate around its canopy, in which other species can develop.

The foliage of mesquite has pinnae and leaves with 6 to 10 mm leaflets and thorns, it produces inflorescences 10 cm long and indehiscent fruits or legumes, also called pods, 12 to 20 cm long. Mesquite flowers from February to April, fruits from April to July, and mature pods can be found from July to September. Each mature pod may contain 10 to 18 oval, flattened seeds, 5 to 7 mm long (Figure 1) (Palacios, 2006).

Figure 1 The mesquite tree (Prosopis laevigata). a) Mesquite tree in sapling, b) Mesquite flower, leaf and thorns, c) Green mesquite pods, d) Mesquite tree with fruit, e) Mesquite sedes

As mentioned above, mesquite was an important resource for the nomadic populations of the north and centre of the Mexican Republic, who developed techniques to use it as human food, in animal feed, in the manufacture of tools, weapons and furniture, to obtain gums, honey, fuel and for medicinal uses, however, its use as human food has been considerably reduced and its use as fuel and in the production of charcoal stands out as its main form of exploitation and use. Today, with the advent of agriculture and the displacement of many wild species used by our ancestors, there is little reason to consider better utilisation of wild species such as mesquite. It will be the better understanding of the characteristics and properties of these species that can recover their relevance and their integration in the strengthening of current food systems.

In the State of Hidalgo there is an extensive region with a semi-arid climate (comprising 30 municipalities and more than a third of the state) that has been historically known as the Mezquital Valley. In this region, where mesquite trees abound, specifically the Prosopis laevigata species, its inhabitants talk about the use of mesquite pods for human consumption, however, in practice it is no longer a current activity and is rather anecdotal. Villagers also refer to the use of mesquite pods as fodder, a practice that is becoming less frequent, but there is one activity associated with mesquite that is active and of great interest, and that is the use of mesquite firewood as fuel in the preparation of the "barbacoa de hoyo" (barbecue pit).

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The Mezquital Valley is a region with special conditions, although it has a semi-arid climate, irrigated agriculture is by far the main economic activity in the region, where up to 20 tons of corn can be harvested per hectare, this important agricultural activity is driven by the availability of an irrigation system.

The irrigation water used in the Mezquital valley is wastewater from the valley of Mexico, about 50 m3/s arrives in the Mezquital valley where it is used in flood irrigation of more than 100,000 hectares, an activity that has been carried out for more than 100 years and has given rise to one of the largest sewage irrigated agricultural systems in the world (Díaz-Batalla *et al*., 2013).

The availability of wastewater in the Mezquital valley allows intensive agriculture and the organic matter load that this water contains favours soil fertility characteristics and crop productivity, however, it also brings other pollutants, mainly a high microbial load, salts, metals and a complex mixture of organic compounds.

In another sense, wastewater implies a source of contamination, which impacts soil stability, aquifers, biodiversity, human health and of course food safety (Díaz-Batalla, *et al*., 2013). These features make the Mezquital Valley a region with a complex food system that departs from the criteria of good agricultural practices, food safety and sustainability.

In this context, mesquite in the Mezquital Valley, despite being in an area that naturally favours its development, has been displaced from daily use by crops such as maize or forage such as alfalfa, which has left it exposed to a degradation of its value and with little reason to include it in the current food system, beyond its use as fuel or firewood.

Despite these conditions, mesquite populations in Hidalgo still dominate the landscape of the Mezquital Valley and maintain a diversity that is manifested in the presence of materials of diverse phenotypes, which are not exempt from pests and diseases incubated by their natural niche and as a result of direct or indirect human influence (Figure 2).

The integration of mesquite into the food system of the Mezquital Valley and the Mexican semi-desert represents a disruptive opportunity in which a species outside the context of current agricultural production, which fixes nitrogen, which is a tree, which grows in the semi-desert and which does not conform to established agricultural cycles, can contribute to strengthening regional sustainability.

Figure 2 Mesquite pods. a) Mesquite pod phenotypes, b) Paxtle (*Tillandsia usneoides*) attached to mesquite

Mesquite pods

Mesquite (*Prosopis laevigata*) produces a fruit or pod that can be seen in its mature state between July and September. A mature pod can be recognised by the loss of chlorophyll and a decrease in moisture content. Mature pods may be straw-coloured, reddish or dark, with more or less twisted shapes. The maturity of the mesquite pod coincides with the rainy season, so a large amount of ripe fruit falls to the ground when the rain falls and gets wet, and the presence of moisture favours the deterioration of the pod and the attack of pests, mainly bruchids (Parra-Gil, 2020).

Harvesting, by hand or with a pole, of the mesquite pod should be carried out taking into account its state of maturity and moisture content, with particular attention to the presence of thorns that can cause injuries. Once harvested, the pod must be dried immediately (humidity less than 12%) and stored in a place protected from humidity and harmful fauna. If these basic aspects are not taken into account, the pod will deteriorate, yields will be reduced and the probability of conditions for the development of fungi and aflatoxin production in the material will increase (Mom, 2020).

The mature mesquite fruit is a legume or pod with particular characteristics. The mesquite pod is an indehiscent fruit, with a developed mesocarp and a woody rind that protects the seed, three characteristics that differentiate it from the rest of the legumes, which in general have dehiscent pods, without a mesocarp and without a woody rind to protect the seed (Figure 3).

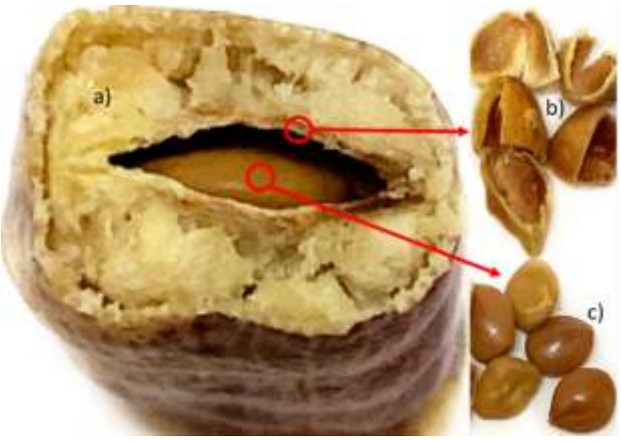

Figure 3 Anatomy of the mesquite pod. a) Cross section of the pod showing the mesocarp, b) Woody bark protecting the seed, c) Mesquite seed

Considering the mature and dry mesquite pod, 16 to 18 % of its weight is constituted by the seed, 30 to 35 % by the woody bark and the rest by the mesocarp (Díaz-Batalla, Hernández-Uribe, Castro-Rosas, Téllez-Jurado, & Gómez-Aldapa, 2018). The annotation and composition of the pod suggests the development of pod utilisation processes aimed at its different fractions, in such a way that the properties of the mesocarp, the woody bark and the seed are used optimally.

The different fractions of the pod have a contrasting composition, while the mesocarp has a large amount of free sugars (45 %), mainly sucrose and its protein content does not exceed 10 %, in the seed the main component is protein with more than 35 % and the woody bark that protects the seed is a material consisting mainly of lignin and cellulose (Díaz-Batalla, Hernández-Uribe, Castro-Rosas, Téllez-Jurado & Gómez-Aldapa, 2018).

When the mesquite pod is considered as a single fraction, integrating the mesocarp and the seed in a single material and excluding the woody bark, it is clear that the result will present an intermediate composition given the sum of these two fractions.

Where protein has levels of between 12 and 13 %, sugars 30 % and fibre around 15 % (Díaz-Batalla, Hernández-Uribe, Castro-Rosas, Téllez-Jurado & Gómez-Aldapa, 2018). Of the sugars present in mesquite mesocarp, sucrose stands out for its quantity, but glucose, fructose and xylose are also present; this quantity and combination of sugars suggest an important potential use of this raw material in the area of industrial fermentations. As an example of the use of this material as a substrate for industrial fermentations, there is a patent application for the process of obtaining a distilled alcoholic beverage called VIGATE (reference to the mesquite laevigata species) (IMPI, 2021a).

In relation to the composition of mesquite seed, its high protein content and amino acid profile have been reported, defining it as a good quality protein, which has appropriate levels of essential amino acids, with particularly high levels of arginine, lysine and sulphur amino acids (Díaz-Batalla, Hernández-Uribe, Gutiérrez-Dorado, Téllez-Jurado, Castro-Rosas, Pérez-Cadena & Gómez-Aldapa, 2018). Seed flour can be processed using emerging and versatile technologies such as extrusion processing to improve its technological and nutritional properties and maintain its nutraceutical properties (Díaz-Batalla, Hernández-Uribe, Gutiérrez-Dorado, Téllez-Jurado, Castro-Rosas, Pérez-Cadena & Gómez-Aldapa, 2018), an example of this is the patent application on obtaining an extruded mesquite seed-based food with functional properties (IMPI, 2021b).

The nutritional profile of mesquite seed and its processing by extrusion has shown its high nutritional and nutraceutical value in preventing the development of dyslipidaemia in a biological mouse model (Díaz-Batalla, Castro-Rosas, Falfan-Cortés, Téllez-Jurado & Gómez-Aldapa, 2021).

The structure and composition of mesquite pods offer opportunities for innovation and the development of new sustainable products to meet the demand for industrial inputs and healthy foods.

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Conclusions

Because of its historical relevance, environmental context, geographical distribution, biological resilience, nutritional value, nutraceutical properties and technological versatility, mesquite and its pods have the potential to be incorporated into the national agroindustry, favouring food sovereignty and the sustainability of the Mexican food system.

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