Review [Revisión]

AGRICULTURAL GENETIC RESOURCES AS A SOURCE OF RESILIENCE IN THE FACE OF THE COVID-19 PANDEMIC IN MEXICO †

[RECURSOS GENÉTICOS AGRÍCOLAS COMO FUENTE DE RESILIENCIA ANTE LA PANDEMIA DE COVID-19 EN MÉXICO]

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SUMMARY

Background: The COVID-19 pandemic evidenced the fragility of the agri-food sector by affecting the food supply chains which directly depend on the health of its main actors. In this context, countries need to rethink the agricultural production models, considering environmental and human health as priorities to achieve food safety. **Aim:** Systematically review the state of the art regarding the role of agricultural genetic resources as a source of resilience in the face of events such as the present pandemic as a point of reflection for the identification of opportunities for the restructuring of regional agriculture sensitive to nutrition for health. **Methodology:** Exhaustive search and analysis of documentary information regarding the effects of COVID-19 on the agri-food sector and the role of agricultural genetic resources in the current pandemic were conducted. Then, through an analysis of the occurrence and association of the main terms addressed in the literature considered, the thematic axes were drawn to address the central discussion of the systematic review. **Results:** Terms co-occurrence analysis corroborated the relevance and pertinence of the topic addressed. Additionally, the importance of the conservation of agricultural genetic resources and implementation of sustainable agriculture models, as a source of resilience to pandemics, was visualized. The discussion addressed the impact of the pandemic on the Mexican agri-food sector and the restructuring of post-COVID-19 agriculture through the nation and nutrition-sensitive agriculture for health approaches. **Implications:** The exhaustive analysis of the relationship COVID-19-agricultural genetic resources-health in Mexico highlights the need for the generation of agricultural policies and the increase in multidisciplinary research that favors biodiversity as a source of sustainability, productivity, and health for agroecosystems and the welfare of humanity. **Conclusions:** A fatalistic scenario for humanity seems to be dissipating in the face of the possibilities of rethinking the economic, social, and agricultural systems from the approaches of the nation and nutrition-sensitive agriculture for health, where, through the responsible use of agricultural resources it is possible to rebuild an agri-food production system with a tendency to resilience to events such as the current pandemic caused by the COVID-19 disease.
Key words: nutrition-sensitive agriculture for health; sustainable agriculture; SARS-CoV-2; agricultural production models; regional and national focus.

RESUMEN

Antecedentes: La pandemia por COVID-19 evidenció la fragilidad del sector agroalimentario al afectar las cadenas de suministro de alimentos que dependen directamente de la salud de sus principales actores. En este contexto, es una necesidad para los países repensar los modelos de producción agrícola, considerando la salud ambiental y humana como prioridades para lograr la inocuidad alimentaria. **Objetivo:** Revisar de forma sistemática el estado del arte con respecto al papel de los recursos genéticos agrícolas como fuente resiliencia ante eventos como la presente pandemia

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como punto de reflexión para la identificación de oportunidades para la reestructuración de una agricultura regional sensible a la nutrición para la salud. **Metodología:** Se realizó una búsqueda y análisis exhaustivo de información documental sobre los efectos del COVID-19 en el sector agroalimentario y el papel de los recursos genéticos agrícolas en la pandemia actual. Luego, mediante un análisis de la ocurrencia y asociación de los principales términos abordados en la literatura considerada, se trazaron los ejes temáticos para abordar la discusión central de la presente revisión sistemática. **Resultados:** Se corroboró la pertinencia y relevancia del tema abordado mediante el análisis de coocurrencia de los términos. Además, se visualizó la importancia de la conservación de los recursos genéticos agrícolas y la implementación de los modelos de producción agrícola sustentable como fuente de resiliencia ante los eventos sanitarios. La discusión abordó el impacto de la pandemia sobre el sector agroalimentario mexicano, y sobre la reestructuración de una agricultura post COVID-19 a través de los enfoques de nación y de la agricultura sensible a la nutrición para la salud. **Implicaciones:** El análisis exhaustivo de la relación COVID-19-recursos genéticos agrícolas-salud en México pone de manifiesto la necesidad de la generación de políticas agrícolas y el incremento en la investigación multidisciplinaria que favorezca la biodiversidad como fuente de estabilidad, productividad y salud para los agroecosistemas y el bienestar de la humanidad. **Conclusiones:** Un escenario fatalista para la humanidad parece disiparse ante las posibilidades de replantear los sistemas económicos, sociales y agrícola desde los enfoques de nación y de agricultura sensible a la nutrición para la salud, en donde, a través del aprovechamiento responsable de los recursos genéticos agrícolas es posible reconstruir un sistema de producción agroalimentaria con tendencia a la resiliencia ante eventos como la presente pandemia causada por la enfermedad COVID-19.

Palabras clave: Agricultura sensible a la nutrición para la salud; agricultura sostenible; SARS-CoV-2; modelos de producción agrícola; enfoque regional y de nación.

INTRODUCTION

Humanity depends on food, and hence, on agriculture as the source of food, nutrients, and nutraceuticals. The right to food was formally established as a human right in Article 25 of the Universal Declaration of Human Rights (1948), approved by the General Assembly of the United Nations (UN General Assembly, 1948). In the Right to Food, Security, and Food Sovereignty framework law, in the XVII Ordinary Assembly of the Latin American Parliament in 2012, a legal framework of reference, establishes for the signatory countries: the development of policies and strategies to guarantee in a way permanent, and as a national priority, "The Right to Food", the food and nutritional security of the populations, for the enjoyment of a healthy and active life (Parlamento Latinoamericano, 2012).

In Mexico, a reform decree published in the Official Gazette of the Federation on October 13, 2011, added a paragraph to constitutional Article 4th to state that "Everyone has the right to nutritious, sufficient and quality food. The State will guarantee it". The importance of food for humanity goes hand in hand with the development and growth of agriculture, and both, play a fundamental role in achieving the development goals of most countries as established in the UN 2030 Agenda and the Sectorial Program for Agriculture and Rural Development 2020-2024 of Mexico.

The crisis created by the COVID-19 pandemic has revealed the fragility of the global system of food production and land use (Davey and Steer 2020). Isolation as a preventive measure for the spread of the virus restricted the distribution and supply of food to cities. These caused economic losses due to the delayed harvests and the expiration products in the field; this highlighted the importance and need to strengthen the use and consumption of local resources (Bahavani and Gopinath, 2020). Thus, resilient food systems based on the sustainable use of resources and a circular economy must be promoted as a measure of prevention and mitigation of this sort of global crisis (Food and Agriculture Organization (FAO), 2018).

In the Mexican agricultural sector, as Victor Suárez Carrera (Undersecretary of Food Self-Sufficiency of the Ministry of Agriculture and Rural Development) commented, in the 20th conference of the Cycle of Food Self-Sufficiency and Technological Innovation with Sustainable Practices: The main challenge of our country is to preserve natural resources and the environment, restore the planet cycles and in parallel produce healthy, nutritious, quality, affordable and sufficient food for everyone. Specifically, agroecology, and sustainable agricultural practices, are the paths to be followed to sustain life cycles and face the effects of soil degradation, environmental pollution, water contamination, and emerging pandemics. A change in the current lifestyle, which lacks respect for ecosystem processes, will prevent future zoonoses (Gómez-Mena, 2021).

Under current circumstances, the present systematic review aims to gather and analyze a broad set of scientific literature to address the effect of the COVID-19 pandemic on Mexican agricultural production. An extensive literature review was carried out to cover the role of agricultural products and food in the health of the population in the face of the pandemic and highlights the importance of agri-food genetic resources and their conservation to face health crises such as the one caused by the SARS-CoV-2 virus. Based on the analysis, the discussion focused on a reflection of the current state of the agricultural production systems, additionally reinforces the value of genetic resources conservation and the importance of sustainable agriculture systems implementation to face health crises such as that caused by the COVID-19 disease.

MATERIALS AND METHODS

The present literature review included a systematic study (Munn *et al*., 2018), using the databases such as Google Scholar, PubMed, ResearchGate, Science Direct, Scielo, Scopus, and Springer Link. The search terms used in English and Spanish were: agriculture, agroecology, biodiversity as a source of resilience, conservation, eating habits during the pandemic, effect of COVID-19, environmental health, food production, food security, food supply chains, human health, Mexico, microbial genetic resources, nutrition to face COVID-19, one health approach, pandemic, plant genetic resources, primary sector, regional and country approach, resilience, sustainable agriculture, and each of its possible combinations as a search engine. As a source of information, only scientific articles, book chapters, official documents issued by world organizations or by the Mexican government and Mexican newspapers were considered, excluding all types of "gray literature" (non-official or peer-reviewed literature). Selected publications were managed with Zotero (2018) software and stored as a RIS format archive. Then, a co-occurrence map of terms in the titles and abstracts of the source publications was created exporting the RIS archive to VOSViewer (van Eck. 2010) and analyzing under the association strength method. The strength of association between the most frequently occurring terms was considered as a central guideline to formulate the discussion of the present systematic review.

RESULTS AND DISCUSSION

The search engines returned a total of 952 publications, of which 136 were selected based on their relationship with the central axis of the review on the role of agricultural genetic resources in the current COVID-19 pandemic in Mexico. In this context, it was observed that the topic addressed is an issue of relevance today since most of the publications were generated in the last three years: 54% were published in the period of 2020 to 2021, 34% from 2010-2019, 10% from 2000-2009, 1.5% from 1990-1999, and 0.5% were published before. Literature from Mexican authorship or dealing with issues of agri-food and health interest developed in Mexico totaled 32%. From these contributions 40% were related to genetic resources, 30% to sustainable agriculture, 17% dealt with COVID-19, health, and food sector, and economy issues during the pandemic, and 13% treated governmental and policies issues.

Terms occurrence analysis identified a total of 3679 terms in the literature and reflected that 51 met the threshold of 10 occurrences as a minimum. The co-occurrence map was build considering only 45% of the most relevant terms based on the strength of its association. The map consisted of 5 semantic clusters in which the terms with the highest occurrence represented the nuclei; based on these central terms, interactions among the different clusters were computed. The terms with the highest occurrence were "plant", "COVID", "agriculture", "strategy", and "soil" (figure 1). Unquestionably, the results obtained in the map of co-occurrence of terms allow corroborating the pertinence and relevance of the topic addressed by the systematic review. From cluster 1, it can be seen that the term "plant" as the nucleus is strongly associated with "microorganisms", "micropropagation", and "yield", and in parallel, is strongly associated with the term "strategy" as the nucleus of cluster 5 which in turn is associated to "conservation" and "challenge". In this context, it is visualized that agricultural genetic resources and their conservation are a central theme for the selected literature. At the other pole, cluster 2 shows the strong association of the term "COVID" as the nucleus, with the terms "Mexico", "nutrition", and "impact", and with "agriculture" as the nucleus of cluster 3, which in turns is strongly associated with terms "food" and "biodiversity". These results show that the effect of the pandemic on the agri-food sector in Mexico is also a central issue, and is directly related to agriculture, food, and biodiversity. Additionally, it is important to mention that the term agriculture is located at the center of the figure, and it interacts with all other clusters. Thus, the map terms occurrences reinforce the central argument of the review, which explores the premise that the agricultural genetic resources managed in a sustainable scheme represent a source of resilience for pandemics as the current caused by COVID-19 (Figure 1).

Impact of the COVID-19 pandemic on agricultural production in Mexico

Mexico is among the 12 economies with the highest agricultural production worldwide. Agriculture employs 8.9 million Mexicans, generating 514,000 million Mexican pesos per year in farm products (SIAP, 2020). To support the growth of the agricultural sector in Mexico, during the scenario of the current COVID-19 pandemic, the Ministry of Agriculture and Rural Development, disclosed and implemented international health measures to reduce COVID-19 infections (ILO, 2020). And in parallel, undertook several measures to guarantee the production of food in Mexico (SADER, 2020); sticking out of them: a) exchange of experiences with Latin America on plant and animal diseases prevention-control during the pandemic, b) agreements between officials, companies,

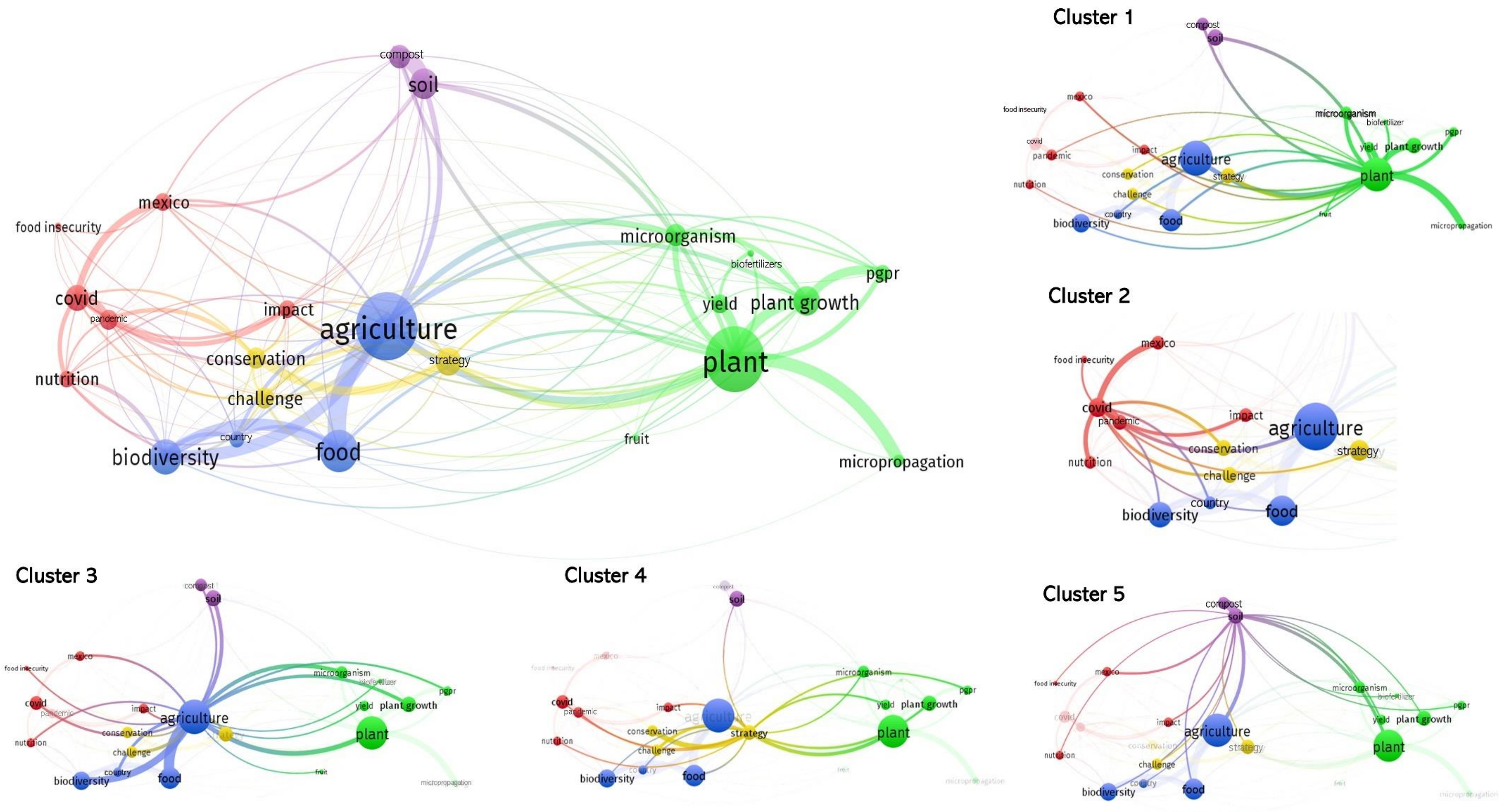

Figure 1. Map of the co-occurrence of terms subtracted from the titles and abstracts of the consulted literature for the elaboration of the systematic review. The map was constructed using the VOSViewer software (van Eck, 2010) fed by RIS archive containing the literature data and analyzed under the association strength method. The spheres represent the most relevant terms and the sizes their relevance according to their occurrence. Lines represent the association among terms and their thickness the strength of the association. Spheres of the same color belongs to the same cluster.

and day-laborers to establish workshops to generate policies in support of day-laborers to face COVID-19, c) meeting with 39 National Product System Committees to generate proposals to deal with the pandemic, d) improvement and optimization of the programs of the Secretary to face the contingency; e) delivery for 22,700 million pesos in support of small-scale producers (Vilaboa-Arroniz *et al*, 2021). Despite the pandemic, the implemented measures, and various economic and political factors, the agricultural, livestock, and agro-industrial sector generated a surplus of 12 thousand 347 million dollars (MD) in 2020, derived from 39 thousand 525 MD of exports and 27 thousand 178 MD of imports. Specifically, the balance of agricultural goods reported a surplus of 5 thousand 820 MD since exports were 53.7% higher than imports. In 2021, the agricultural and agro-industrial balance of January and February had a surplus of 1,704 MD (SIAP, 2020; Romo-Gonzales, 2020). For example, the products that increased their export numbers the most were avocado (24.77% / 1,289 million dollars), tequila-mezcal (35.21% / 738 million dollars) and tomato (13.09% / 1,019 million dollars) (BANCOMEXT, 2020). This production of the agricultural sector was achieved by the implementation of several mechanisms by all the farming systems, along with collective action and organization of farmers, to cope with the COVID-19; these mechanisms include the innovation of alternative value chains, food and new agricultural products, delivery systems and the exponential use of digital means to continue with the viability of the different agricultural systems. However, these new transformed farming systems, which have greater resilience and sustainability must be strengthened and diversified in the post COVID 19 era (Lopez-Ridaura *et al*., 2021).

As Victor Manuel Villalobos Arambula (Secretary of Agriculture and Rural Development) recently pointed out: It has been a priority for the Mexican Government to generate synergy with agricultural, fishing, and aquaculture producers, to maintain the functioning of the productive national chain and guarantee the supply of food in the national market and satisfy the demand for Mexican products in international markets (SENASICA, 2021). Although all types of farming systems (i.e., corporate agricultural production systems, to small and medium scale entrepreneurs and smallholder subsistence farm households) were impacted, more or less severely, by the different measures implemented by governments such as reduced mobility, closure of public and private venues and restrictions in borders (Lopez-Ridaura *et al*., 2021). The crisis caused to agriculture in Mexico by the COVID-19 pandemic focuses on the interrelationships of the national market, mainly in the medium and small entrepreneurial farming systems. The links of the agro-productive chain were affected in the supply centers, the intermediation in the commercialization and transportation of farm products (Blanco, 2020). Not mention the risk of contracting the infection on the part of the workers of the field. A good practice would be to identify collection centers close to the producers, develop storage facilities as platforms of reception warehouse systems where farmers can deliver their products without going to the retired collection and supply centers. Fundamentally, the agro-productive chains must get strengthened to avoid intermediaries and displacements over long distances to ensure the provisioning of fresh and sufficient food. In this context, plots, rural and urban orchards, farms, or other means of food production at the local level must be promoted and maintained as an asset for the food autonomy of each region (Altieri and Nicholls, 2020). For example, in response to COVID-19, the family farming and the agroecology movement in Mexico and other Latin-American countries, implemented or adapted four initiatives: a) strengthen direct producer-to-consumer food sales, b) short value chains that linked rural and urban organizations and individuals supported by national or local governments, readapted through new health and safety protocols, c) newly developed support and training programs on sustainable food production for self-consumption or local commerce, in rural, urban or peri-urban settings, and d) food assistance and aid initiatives focusing on vulnerable populations, relying on solidarity networks associated with the agroecological movement (Tittonell *et al*., 2021). Additionally, new ways of commercializing can be created or developed; for example, the producers can be closer to the consumers through social networks, and the consumers can establish closer relationships with the producers and start long and sustainable cycles of consumption that need to be linked with economic agents, institutions, productive organizations, and build a legal institutional framework (Velázquez-Salazar and Pérez-Akaki; 2021). As was evidenced with the commercial applications of Smattcom and Jüsto, and the governmental applications of Mercados, Produce and Padrón de productores, that were developed for the acquisition of food through the Internet in Mexico (Olmedo-Neri, 2021). Also, to solve the problem of the actual crisis in the chain and to open new marketing methods, the boosting of Protected Designation of Origin (PDO) can be a good strategy, as was developed recently in the Coffee Pluma geographical region in Oaxaca (Velázquez-Salazar and Pérez-Akaki; 2021).

Food security in the face of the COVID-19 pandemic

Throughout the history of humankind, natural, social, health, and economic crises have been demonstrated to affect food security directly. For instance, the pandemics of the European Middle Ages, Imperial China, and the influenza of 1918; as well as the economic recessions as the Great Depression of 1930, those of 1974, and 2007-2008. Despite these historical facts, the lack of standardized public policies regarding food security has been present in all the world economies (ONU, 2020; Rummo *et al.*, 2021; Gundersen and Ziliak, 2015; Mook *et al.*, 2016). Currently, this has been further evidenced by the COVID-19 pandemic, by affecting the accessibility and availability of food and increasing food insecurity rates, especially among children, and whose consequences as the increase in malnutrition and hunger, will not be known for a few years (Runkle and Nelson, 2021). In addition, world and national statistics reflect this crisis, and confinement has modified population eating habits. On one hand, food insecurity due to unemployment and panic hoarding that results in shortages. And in other increasing in diet both, healthy and unhealthy mediated by economic strata, by cultural level, by health status, by depression and stress due to confinement and other social factors caused by de pandemic (Belanger *et al.,* 2020). In general, in Latin America, there was a reduction in consumption of meat and fish and fresh fruits and vegetables, as well as an increase in the consumption of prepared and packaged foods, as an adaptation strategy to a significant loss of income and the reduction of job opportunities in the countries as an effect of pandemics (Cano *et al*., 2021). In Mexico, several studies reflect these changes in the Mexican population. The National Institute of Public Health (2020) in the study on the effect of COVID-19 contingency on the consumption and purchase of food by Mexican adults, identified that half of the sampled population decreased the family income in the pandemic, which favored the purchase of cheaper food and at times decreased the amount of food or they stopped some food consumption. As well, Boix-Cruz (2021), conducted a study in the states of Puebla and Oaxaca, pointing out that moderate to severe food insecurity was present in the households surveyed. Otherwise, Villaseñor-Lopez *et al*. (2021) in a research of the lifestyle and nutrition changes during the SARS-CoV-2 (COVID-19) confinement, reported that 44.4% of the female population and 47.1% of the male population felt that their feeding had been affected due to confinement, with an increase in the consumption of sweets and desserts in 39% of men and 51.6% of women, an increase in the consumption of sugary drinks and junk food by about 30% for men and women, and of the total of participants 35.8% said they had reduced the consumption of healthy foods, only the 25.6% of the population studied increased the consumption of junk food. These concrete actions, the new obligated lifestyle, and the changes in food consumption are the result of the ravages of socio-economic disparity and food insecurity caused by pandemics such as the one currently experienced, and directly lead to malnutrition, furthermore, aggravate conditions of vulnerability in the population. Shortage, socio-economic disparity, and poor nutrition are direct consequences of the current pandemic and make food insecurity tangible.

Thus, FAO calls for immediate action in seven key priority areas to minimize the detrimental effects of the COVID-19 pandemic on food security and nutrition. And to transform global food systems to increase resilience, sustainability, and equality (FAO, 2020).

1- Reinforce the Global Humanitarian Response Plan for the COVID-19 pandemic.
2- Improve data for decision-making.
3- Ensure economic inclusion and social protection to reduce poverty.
4- Reinforce trade and food safety standards.
5- Enhance the resilience of small farmers for recuperation.
6- Prevent the next pandemic of zoonotic origin by applying a reinforced “One Health” approach.
7- Promote the transformation of food systems by the regional and country focusing.

In this sense, the Mexican government recognizes in the Sectorial Program for Agriculture and Rural Development the need to achieve food self-sufficiency, to contribute to the well-being of the population through inclusive agriculture and to change conventional practices to sustainable production schemes (DOF, 2020a). Thus, specifically, the fourth, fifth, sixth, and seventh areas, in an explicit form, highlight the importance of reinforcing agricultural production in local and one health approaches. In other words, in this globalized “new world” it should be noted that, in biological matters such as food production, nourishment, and nutrition, thinking local is the point of improvement to achieve resilient food systems. In this way, genetic resources, such as crops, local varieties, and alternative management strategies to the traditional ones, that promote the pathway towards regional food sovereignty, become particularly important. In addition, using local genetic resources, traditional and alternative practices are also the way to regain the balance of agroecosystems, come near to food security, and consequently, maintain human welfare. Some examples of sustainable, fair, and inclusive agricultural systems that have been developed in Mexico are coffee production systems in Chiapas, and maize in Tlaxcala and Puebla (Toledo and Barrera-Bassols, 2017).

Agri-food genetic resources participation in food security

When considering that “the diversity of crops is the base of a balanced and nutritious diet” (Keding *et al*., 2013), must be highlighted that the dietary diversity depends on both the diversity of crops and the genetic diversity within them. For instance, despite the 7000 species that have been cultivated or collected for food by humanity, currently, less than 150 are commercially cultivated, 30 cover 95% of human food energy needs, and 3 of them, wheat, rice, and corn, provide more than 50% of the world's supply of human protein and dietary energy (Salaverry, 2012). Thus, thousands of plant species and varieties are considered minor crops, some with high nutritional values, are underused, and the same happens with locally adapted crop varieties.

The biodiversity of the agri-food genetic resources must be considered essential for food security and nutrition and to counteract the unfavorable effects of the simplified agricultural systems based on monoculture and the erosion of the food systems. Additionally, agri-food biodiversity is a mean to guarantee the conservation of agroecosystems (Johns and Sthapit, 2004). Although this topic is still slightly included in nutrition programs, there is a solid world research line focused on the nutritional value of food biodiversity, and its consumption on nutrition programs; as the research of Keding *et al*. (2013) about nutrition-sensitive agriculture and sustainable diets, as well the research of human nutrition without degrading land resources (Amede *et al*., 2004), the study of the effects on dietary consumption of food environment (Herforth and Ahmed, 2015), and the analysis of the role of food science and technology in humanitarian response (Bounie *et al,* 2020).

All countries face the challenge of developing agriculture that aims not only at productivity and sustainability. But also, agriculture must focus on balanced nutrition or what has been called the paradigm of productive, sustainable, and nutritious food systems (Graham *et al.,* 2001). As agri-food genetic resources are the basis for the adoption of agricultural models sensitive to nutrition and health, considering the use of renewable and non-renewable resources, the new food systems must be based on sustainable agriculture that conserves and uses biodiversity as a source of nutritional security and, thus, mitigates malnutrition (Underwood, 2000). Also, is necessary to develop policies to promote the conservation and responsible use of the agri-food genetic resources as a mean to address the nutritional and health problems of the population, and additionally, these can be used to promote public initiatives to influence the behavior of food consumption that favors to maintain or increase the use of agri-food biodiversity.

The effect of food and agricultural practices on human health

The absence of an effective treatment or a complete and effective vaccination program for COVID-19 disease for the entire population encouraged the population to resort to continuing with the prevention measures such as social distancing, the continuous sanitization of the person, objects, and spaces, and the use of masks and other accessories; since, as predicted, stopping these practices causes new waves of the disease (Teófilo-Salvador, 2021; Ortigoza-Capetillo and Lorandi-Medina, 2021). Notwithstanding, the effectiveness of these methods depends on the existence of the correct usage protocols, the percentage of social compliance, the level of toxicity and contamination that each of these methods carries (Pradhan *et al.,* 2020). Adequate nutrition has been demonstrated to be a key factor that provides individuals with resilience towards diseases: the type, quantity, and quality of nutrients from different foods, together with the microbiota established in the gut, facilitate the modulation of cellular processes that give way to the immune responses to face the imbalances caused by the SARS-CoV-2 virus (Aman and Masood, 2020). Current medical research has conveyed that the risk of infection can decrease by the consumption of nutraceuticals from food such as omega 3, eicosapentaenoic, and docosahexaenoic acids. Also, the consumption of antioxidants contained in agricultural products such as fruits, vegetables, and medicinal plants, can limit the proliferation of the virus and help to interrupt inflammatory processes (Tahir *et al.*, 2020). Nutrients (carbohydrates, proteins, lipids), nutraceuticals (carotenoids, flavonoids, terpenoids), and probiotics (*Lactobacillus casei, Bifidobacterium bifidum*, *Streptococcus salivaris* sbsp. *thermophilus*) capable of providing health benefits, comes from food, and in turn, these are originally from the field, from food genetic resources (Witkamp and van Norren, 2018). However, food can lose its properties, not reach adequate content, or even be unsafe, when accompanied by traces of molecules of harmful compounds under high performance food production systems.

Since the beginning of the use of synthetic agrochemicals in agriculture, the effects of these substances on the environment and human health have reached significant dimensions. Thus, agrochemicals currently used in agricultural production are an obstacle to achieving nutrition- and health-sensitive agriculture. To achieve adequate healthy food production, the methods, techniques, and materials involved must change as well. Even is possible to generate sustainable technology aimed to prevent biodiversity loss and maintaining environmental and human health (Fernandes *et al*., 2021).

Sustainable nutrition-sensitive agriculture for human health

The COVID-19 crisis has intensified, on the one hand, the fragility of the global food and land use system (Davey and Steer, 2020); and on the other, that the nutritional content of food added to a functional microbiota capable of associating to the gut (Tahir *et *al*., 2020; Mahad and Masood, 2020) is a crucial tool that should not go unnoticed by the clinical and dietary nutrition plan, as a basic service of health systems (Charro-Salgado, 1999). This should redirect humanity to the implementation of food systems accompanied by methods and technologies that allow improving food production from a multidisciplinary perspective. Additionally, governments must foster a conducive social-economic-political environment, where agriculture may be required to be part of the drive for fair production. In these proposed models, the same importance must be given to the nutritional dimension and the diversification of production, as the importance given to productivity and short-term profits, without overlooking attention to the health of the soil, the sustainable use of the productive sources (water and soil), and the preservation of species with the potential to provide food, nutritional and nutraceutical benefits to humanity (Bhavani and Gopinath, 2020), as traditional pastoral landscapes in Europe (Finck *et al*., 2002).

The agriculture post-COVID-19 pandemic must leave behind the conventional food production schemes that have been used since the Green Revolution since its approach does not consider that agriculture is an ecosystem service, and by disrespecting this premise, the agricultural activity results in the depletion of productive resources, the loss of biodiversity and the dysfunctionality of agroecosystems (Power, 2010) (Figure 2A).

To restructure the new agriculture must be based on two main approaches. The first named the "regional and country" approach, consider environmental and agroecosystem health, including food safety systems as a priority in such a way that under these concepts the risks of emerging pandemics will be limited, the local economy is strengthened, and vulnerability will reduce, thus, local agriculture would serve as a pillar to achieve regional food security (FAO, 2018). The second, known as nutrition-sensitive agriculture for health, is an inclusive approach that seeks to make the most of the genetic resources adapted to the characteristics of each region. The aim is to address the nutritional needs of the local population, scheduling the agricultural production system to provide a balanced diet of nutrients and nutraceuticals that promotes health (Bhavani and Gopinath 2020) (Figure 2B). Both approaches, converge on the adoption of agriculture based on agroecological practices oriented to the conservation of productive means and agro-food biodiversity (Altieri and Nicholls, 2020). In this sense, is pertinent to clarify is not proposed to put aside commercial agriculture through which foreign exchange is generated and adopt a totalitarian scheme of traditional or conservation agriculture. The Mexican government has established the need to produce healthy, nutritious, quality, affordable and sufficient food, through sustainable agricultural practices, this involves the use of biological, technological, and traditional techniques with multisectoral and multidisciplinary participation. A proposal is a development, on the one hand, of commercial agriculture for export, which adopts sustainable production models that allow decrease environmental impact. While on the other, promote regional and nutrition-sensitive agriculture for health approaches to strengthening and improving food production and distribution chains to pursue food self-sufficiency, and consequently a greater degree of resilience to events such as the present pandemic. To achieving these schemes, agri-food genetic resources play a crucial role as the source of food, materials, energy, and even to produce free-pollution inputs for the field.

The aforementioned approaches promote the implementation of production techniques and models that have been the focus of attention for the scientific community in the last decades. As an object of study in Mexico, the literature shows promising results, which makes some of these ideal prospects for the restructuring of a functional agriculture post-COVID-19 pandemic.

Tillage techniques as conservation or minimum tillage focus on soil and water conservation. These promote carbon and nitrogen retention by favoring biogeochemical processes related to the microbial resource that inhabit the soil. Specifically, conservation tillage considers the permanence of at least 30% of the crop residues on the soil until the next sowing. Both techniques are efficient in the short term for recovering organic matter and native microbiota; in the medium-term increases productivity on the agricultural system; and in the long term restores the natural cycles and functions of the soil (Baker *et al*., 2009). For instance, in Mexico, the milpa system with the simultaneous planting of different varieties of native corn in association with other crops, the practices of minimum tillage, and the zero presence of agrochemicals, have maintained a very high diversity of animals, plants, and microorganisms in the soil of the ecosystem (Rocha and Gastélum, 2020); which allows the soil associated with maize to present a dynamic microbial diversity on short-term scales (Rebollar *et al*., 2017).

The ecological farming system avoids the usage of synthetic supplies and is principally based on crop rotation and incorporation of crop residues, fertilizers of animal origin, organic farm waste, and biological systems of nutrient cycling and plant protection, increasing nutrient and antioxidant content in crops (Patle *et al.*, 2020; Petkova *et al.*, 2020). This system considers plants as part of a complete system within nature and is based on the improvement of biological diversity in the field to alter the habitat of pests and

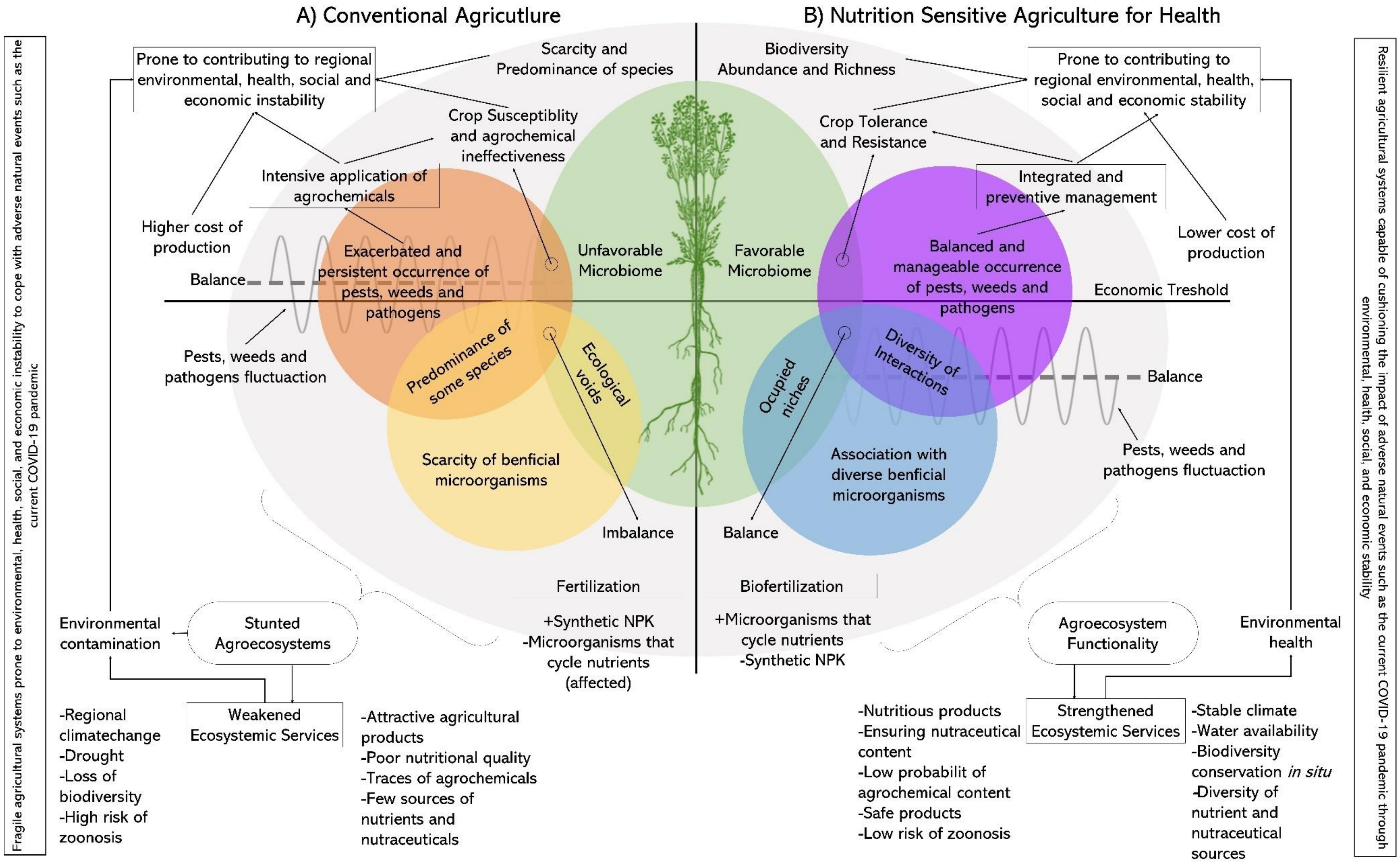

Figure 2. Comparison of a conventional agriculture-based system against local nutrition-sensitive agriculture for a health-based system. A) Conventional agriculture-based system. (Full figure description is presented in the next page).

Figure 2. Comparison of a conventional agriculture-based system against local nutrition-sensitive agriculture for a health-based system. A) Conventional agriculture-based system. Based on high inputs of agrochemicals which alter the microbiota associated with the plan. Promotes the predominance of species that could behave as plant pathogens due to ecological gaps and the lack of biotic interactions with other microorganisms. Over time these populations become tolerant to agrochemicals, therefore their occurrence is exacerbated, and their natural fluctuations reach concentrations making necessary their control by agrochemicals, exceeding, in most cases, the economic threshold raising the cost of production. Under this scheme, ecosystems atrophy, therefore ecosystem services are wakened, and pollution levels increase, promoting the loss of biodiversity and resulting in environmental, health, social, and economic instability. The possibility to face adverse natural events such as the present COVID-19 pandemic is reduced. **B) Nutrition-sensitive agriculture for the health-based system.** Based on the responsible use of local genetic resources to increase the diversity, availability, and accessibility of foods that meet the nutritional and nutraceutical needs of the population produced through sustainable means. This scheme promotes the diversity of species to ensure that more than one can cover strategic niches and through diverse biotic interactions established among them, promote the stability of the agroecosystem. The diversity of microorganisms' populations promotes a natural balance over time avoiding exacerbated fluctuations. Thus, the costs are maintained without exceeding the economic threshold allowing better profits. Additionally, the functionality of the agroecosystems is maintained, meanwhile, ecosystem services are strengthened, preserving environmental health and biodiversity. These schemes promote economic, health, environmental, and social stability and provide resilience to communities towards unfavorable events such as the current COVID-19 pandemic.

diseases and on the maintenance and replenishment of soil fertility. Ecological farming considers soil and environments as a source to be used for the well-being of future generations; hence, employ renewable resources, reduce environmental pollution, recycle plantation, household, industrial and other wastes. Ecological farming can be a long-term alternative against the industrial-high performance food production systems.

Sustainable agriculture is part of a broader movement, this recognizes that natural resources and the limits of the economic growth are finite, encourages equity in resources assignation, and considers long-term interests (preserve the topsoil, biodiversity, and rural communities) rather than just short-term interests as the profits. Sustainable agriculture is also local and dynamic; hence it evolves to respond to changes in a physical environment or social or economic contexts. Further, is holistic in the sense that takes a system-wide approach to solve agricultural management problems.

A sustainable approach places agriculture as the center of social, environmental, and economic well-being within the whole food system (Horrigan *et al*., 2002). Sustainable agriculture principles are based on the integration of ecological and biological processes as N_2 fixation, nutrient cycling, and soil regeneration, together with the reduction of harmful pollutants, and integration of implementations to solve agriculture problems, as control plant pests and diseases, water and soil manage, etc. (Seleiman and Hafez, 2021); several new technologies and methodologies have been applied to reach this goal at different scales of production, from the use of superabsorbent biochar composite grafted on carboxymethyl cellulose for soil water retention capacity (Elsaeed *et al*., 2021), development of bio-tillage cover crops (Zhang and Peng, 2021), design of future crops (Tian *et al*., 2020), use of bioestimulants for seed germination (Maliki *et al*, 2021), use of bioinoculants from native or foreign origin (Figueiredo-Santos and Lopes-Olivares, 2021) or engineering origin (Haskett *et al*., 2021), development of microbial products and microbiomes engineered-microbial communities capable of delivering agronomic solutions (Trivedi *et al*., 2021), use of nanotechnology in seed nano-priming (do Espirito Santo-Pereira *et al*., 2021), use of insect frass as organic fertilizer (Poveda, 2021), development of biosensor technologies, including isothermal amplification, detection of nanomaterials, paper-based techniques, robotics, and lab-on-a-chip analytical devices to monitor crop development including early detection of phytopathogens (Ali *et al*., 2021), use of algal biochar for carbon sequestration and greenhouse gas mitigation (Mona *et al*., 2021); until the generation of conceptual frameworks and developmental approaches to find the most appropriate levers for a diversity of farmers and farming systems (Slimi *et al*., 2021).

The use of bioinoculants, organic amendments, and plant extracts are other biotechnological strategies used in agricultural production to reduce the use of agrochemicals. Bioinoculants are elaborated using microorganisms of diverse origins: crops, different soil types and precedence, fresh and seawater, extreme natural or artificial environments, conserved areas, among others; bioinoculants are meaningful methods to incorporate probiotics into agricultural soils (Yadav *et al.*, 2017). Bioinoculants improve soil and subsoil structure, the availability of nutrients from soil minerals, and the water infiltration into soils (Srivastava and Ngullie, 2009). The incorporation of microorganisms into the soil using this technique favors soil health and simultaneously is possible to control plant diseases and pests and induce tolerance to unfavorable abiotic factors (Enebe and Babalola, 2018; Etesamia and Maheshwarib, 2018; Vurukonda *et al*., 2016). In addition, microorganisms are capable to stimulate and elicit secondary metabolisms in plants, therefore, higher contents of nutraceuticals are obtained in fruits and vegetables, promoting better health for the consumer (Ganugi *et al.,* 2021). In Mexico, there are several biological products developed by Mexican companies that are focused on a few microbial genera, as *Bacillus*, *Trichoderma*, *Rhizophagus,* and *Bauberia* (Chavez-Diaz, *et al*, 2020); in the same way, numerous strains and technologies have been implemented on the development, innovation, and validation of bioinoculants, with successful results (Cruz-Cardenas *et al*., 2021). However, the acceptance and application of this agro-biotechnology will undoubtedly increase, due to its effectiveness, low cost, and zero negative impacts on the environment (known so far), as well as, for the goal of the national biofertilizer program to promote sustainable agriculture (Cruz-Cardenas *et al*., 2021), that has been implemented in the national "Production for Wellbeing Program", that intend to generate a self-production of bioinoculants by agricultural producers.

Among organic amendments, compost is one of the most used. Composting refers to the controlled biological decomposition process that turns organic matter into a stable product like hummus, free of odors and pathogens (Sadik *et al.,* 2010). Compost contributions to soil are diverse, nutrients supply, and carbon sequestration are the main benefits. However, pests and diseases suppression, improvement of soil quality, recovery of agroecosystems biodiversity, increase in crops yield and nutritional content, improved humidity retention, and decrease of soil erosion are also contributions from compost use (Martínez-Blanco *et al*., 2013). In Mexico, the use of compost has been largely studied; e.g., the composting of sugarcane waste in southeastern Mexico (Pérez-Méndez, 2011), the effect of short-term compost effect on sandy soil in the valley of Mexico (de Léon-González *et al*., 2000), compost made with green waste as an urban soil improver (Cantero-Flores *et al*., 2020). Another organic fertilizer is bokashi, a method of preparing solid organic compost of Japanese origin, where aerobic fermentation of waste occurs through the inoculation of microorganisms that accelerate the process by shortening the time to obtain the fertilizer. In Mexico, bokashi has been evaluated in the cultivation of chili, habanero pepper, broccoli, onion, and pine replanting, obtaining excellent results (López-Arcos, 2012; Jaramillo-López *et al*., 2015; Alvarez-Solís *et al*., 2016; Peralta-Antonio *et al*., 2019).

Another green technology with encouraging results is the use of plant extracts to control crop diseases and pests in the field and postharvest. Plants have protected themselves from pathogens and pests since the beginning of agriculture through synthesizing secondary metabolites that serve as defense mechanisms; flavonoids, phenols, terpenes, alkaloids, lecithin, and polypeptides are among the substances that stand out. In addition, most of the compounds obtained from plants are biodegradable, safe, and do not represent a risk for ecosystems or human health (Celis *et al.*, 2008; Nava-Pérez *et al*., 2010). In México, several studies have been focused on the control of plant pests and diseases; *Salmea scandens* extracts to inhibit the growth of *Fusarium oxysporum* and *Alternaria solani* of tomato (Salas-Marina *et al*., 2021), extracts of Larrea *tridentata* and *Hymenoclea monogyra* control *F. oxysporum* f. sp. basilici in basil (Holguín-Peña et al., 2021), extracts of *Baccharis salicifolia* and *Lepidium virginicum* as herbicides on tomato cultivation (Miranda-Arámbula *et al*., 2021), the acaricide activity of *Lippia berlandieri* and *Azadirachta indica* (Ruiz-Jimenez *et al*., 2021), among others.

Meanwhile, nanomaterials are new technologies recently to the field, their effect on plants include the increase of germination, biomass, root length, and sprouts rates and percentages. Also, nanotechnology seeks to increase the efficiency of synthetic fertilizers through the help of nano clays and zeolites, the recovery of soil fertility through the slow and prolonged release of nutrients, and the improvement of physiological parameters as photosynthetic activity and nitrogen metabolism. In addition, is known that nanotechnology can be used to liberate for the controlled release of agrochemicals or nutrients in a site-directed manner to improve the plants' resistance to diseases or plant nutrition and growth (Agrawal and Rathore, 2014). Nano fertilizers reduce the toxic activity of some nutrient sources to the soil, minimize the possible adverse effects associated with agrochemicals overdose and reduce the frequency of the applications (Manjunatha *et al.*, 2016). In Mexico, research is also being carried out on nanoparticles that can help the development of sustainable agriculture. The use of zinc oxide nanoparticles proved to increase yield bell pepper production (Uresti-Porras *et al*., 2021), zinc oxide and titanium dioxide nanoparticles had exerted control against *Bactericera cockerelli* as a pest of tomato (Gutiérrez-Ramírez *et al.*, 2021), and zinc oxide nanoparticles have antifungal activity towards *Fusarium oxysporum-Solanum lycopersicum* in tomato-fusarium pathosystem (González-Merino *et al.*, 2021).

Micropropagation of plant tissue is poorly explored in the world, sometimes for the risks associated with *in vitro* collections (contamination occurrence, correct identity of accessions, somaclonal variation, cellular aging and senescence, and safety duplication) (Engels and Ebert, 2021), and also because micropropagation studies are limited only to a few genera of medicinal, wood and rubber yielding, and high-production crops (Kondamudi *et al*, 2009); nonetheless, is another biotechnological tool with great potential. Micropropagation is based on the *in vitro* culture of small portions of plant tissues and organs in defined culture media in sealed containers under controlled conditions. This technique offers diverse advantages such as large-scale clonal propagation of plants in relatively short periods (Loberant and Altman, 2009). Allows choosing mother plants that produce foods with specific nutritional and nutraceutical characteristics. These plants will give rise to many pathogen-free plants that in turn will express their genetic potential in the field. Also, this technique allows ensuring the obtained food does not represent a risk to human or environmental health (Loyola-Vargas and Ochoa-Alejo, 2012; Thorpe, 2012). However, in Mexico there have been studies on micropropagation on several crop, as *Physalis angulate*, *Agave angustifolia* and *Carica papaya* (Ramiréz-Hernández *et al*. 2021; Monja-Mio *et al*., 2021; Romo-Paz *et al*., 2021).

During the last decades, the aforementioned agricultural production methods and techniques have been scientifically documented worldwide, obtaining encouraging results in most cases (Table 1). The need of the Mexican country for nutrition-sensitive regional agriculture to ensure the health of its inhabitants requires promotion from Mexican government institutions, and support research centers aligned to these approaches. In this way will be possible to develop local cost-effective and free-pollution technologies, in addition, these will carry the promotion of the responsible use of genetic resources and food sovereignty for each region in Mexico.

Conservation of agri-food genetic resources

The COVID-19 pandemic emphasizes the importance of conserve genetic resources involved in food security. The importance of establishing several seed, animal and microbial germplasm banks has been promoted from many years. In response to this call, various germplasm banks have been established such as the banks of the CGIAR research centers that are found in several countries around the word (Börner *et al*., 20212), the National Bureau of Plant Genetic Resources in India, The Svalbard Global Seed Vault in Norway. In Mexico, the government established the National Genetic Resources Center (CNRG for its acronym in Spanish; SAGARPA, 2012) as a key component strategy for the long-term conservation and sustainable use of all types of genetic resources involved in food security. Technology generated through responsible use of genetic resources enables the production of healthy crops and safe foods with increased nutritional and nutraceutical content and reduced agrochemicals traces. The conservation of agri-food genetic resources in Mexico concerns natural protected areas (*in situ* conservation) and germplasm banks (*ex-situ* conservation). The implementation and strengthening of this activity become more important every day. Currently, the diversity of agri-food genetic resources (plant and microbial) is declining due to the destruction of habitats, the inadequate and abusive use of agricultural supplies (synthetics), and climate change effects, among other factors (FAO, 2019). Is important to consider in the short-term the preservation of intact regional agricultural enclosures directed to conserve genetic resources. In addition, these lands might be directed to develop strategies for the responsible use of diverse types of genetic resources. Such activity must be valued and implemented by the genetic resources conservation centers since will allow agricultural scientists to have a greater understanding of the plant-microbe-environment interaction, and in this context, provide improvements and solutions for farmers, industry, consumers, and the entire agri-food sector. The genetic resources conservation centers are a key link in the food chain to ensure present and future food security (Soltanighias *et al*., 2018).

Germplasm banks represent the best strategy to conserve the diversity of plant species. Germplasm conservation aims to safeguard the genetic diversity available for future use, and in the worst case, have a safeguard of genetic resources to reincorporate endangered species. Germplasm banks maintain national and international collections of the most important food species for the benefit of humanity. These collections constitute the most complete catalog of native genetic diversity offering a valuable resource to face challenges such as climate change and meet nutritional demands in the face of population growth. Conservation of plant tissue cultures *in vitro* has proven to be a valuable complement for germplasm banks (Lascuráin *et al.,* 2009). The monitoring with molecular techniques allows to ensure the conservation of a representative sample of the genetic diversity of the agri-food genetic resources in the collections and allows to control of the genetic integrity of the conserved germplasm (Engels and Ebert, 2021).

The long-term conservation of microbial genetic resources is crucial to provide relevant solutions to the problems of humanity. Conservation of microbial genetic resources through *in situ*, *ex situ* and *in-factory* strategies, is one of the most important activities of

Table 1. Alternative techniques and methods of agricultural production that enhance the use of genetic resourses for a nutrition-sensitive agriculture for health.

Agricultural Method / Technique	Genetic Resource		Principal Findings	References
	Classification	Organisms		
Inoculation of microorganisms	Microbial and Plant GR	*Bacillus subtilis x Citrus sinensis*	Inoculation of *B. subtilis* in Tarocco blood oranges reduced synthetic fertilizer input, improve roots development, and availability of P in soil. These effects improved the quality of fruit by inducing uniform coloring of the fruit, reducing the titratable acidity, and promoting a better nutritional content compared to the treatment with high doses of fertilizer.	Qiu *et al*., 2021
Inoculation of microorganisms	Microbial and Plant GR	*Anabaena variabilis x Oryza sativa*	Plant growth promotion, yield increase, decrease in synthetic N fertilizer usage, and efficient control of blight pod and bacterial blight in 62% and 45%, respectively, were achieved by inoculating A. variabilis SCAU30 in rice plants.	Bao *et al*., 2021
Inoculation of microorganisms	Microbial and Plant GR	*Trichoderma virens, T. harzianum x Lactuca sativa, Eruca sativa*	*Trichoderma*-based products improved N uptake even in suboptimal levels of N. Both fungal products increased marketable fresh biomass in lettuce and arugula. Also, mineral content and ascorbic acid content were higher in inoculated plants in comparison with non-inoculated plants, even in unfertilized treatments. In addition, rhizospheric prokaryotic and eukaryotic biodiversity was improved.	Fiorentino *et al.*, 2018
Conservation Tillage	Plant GR	*Zea mayz*	As a sustainable technique, the conservation tillage obtained the best results increasing maize crop yields up to 5.0-7.9 kg ha^{-1} grown under rainfed conditions.	Olguín-López *et al*., 2017
Nanoparticles	Plant GR	*Capsicum annuum*	Plants exposed to 2.5% of NpsZnO + Ag recorded higher growth and biomass production compared to control plants, showing significative higher values in height (16.8%), leaf area (30.3%), total biomass production (59.5%), root dry biomass (112.5%), stem dry biomass (76%), root length (24.4%, chlorophyll content (8%) and the number of leaves (32.6%).	Méndez-Argüello *et al*., 2016
Nanoparticles	Plant GR	*Capsicum annuum; Solanum lycopersicum*	Copper nanoparticles absorbed in chitosan hydrogel added to plants before to transplantation induced an increment of lycopene and antioxidant activity in tomato fruits. Meanwhile, in Jalapeño pepper fruits, an increase of antioxidants as phenols and flavonoids were recorded; additionally, fruits lose less weight in the post-harvest stages.	Juarez-Maldonado *et al.*, 2016.; Pinedo-Guerrero *et al.*, 2017
Vermicompost	Plant GR	*Aloe vera*	Vermicompost incorporated into the production scheme of *Aloe vera* resulted in an increase in the thickness of the leaves and improved the quality of the content of total solids, precipitable solids in methanol, and carbohydrates, in the leaf gel.	Aba-Guevara *et al*., 2016

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Agricultural Method / Technique	Genetic Resource		Principal Findings	References
	Classification	Organisms		
Use of by-products of agri-food sector	Microbial and Plant GR	Native microbiota; *Brasica oleraceae* var. *Acephala* cv. 'Manteiga'	Multiple benefits were obtained by applying milk-based products and a biofertilizer based on cow manure. Control of black rot up to 56% and 44% where observe in plants sprayed with milk-based products and biofertilizer, respectively. In presence of plant pathogen, milk-based product increased yield, antioxidant activity, crude protein and fiber content. Meanwhile biofertilizer increased expression of defense-related features. Both showed promising results to control black rot and improved food quality and nutritional and nutraceutical values.	Nuñez *et al.*, 2021
In vitro culture	Plant GR	*Ocimum basilicum* L. var. Purpurascens	The study demonstrates the potential of in vitro techniques to increase the content of antioxidants in basil. When callus stimulated through different sustainable methods achieves to increase to a 2.3-fold increase of rosmarinic acid in comparison to control. Besides, chichoric acid and anthocyanins content increased up to 4.1-fold greater.	Nazir *et al.*, 2020
In vitro culture	Plant GR	*Fragaria x ananassa* cv. Alba	An alternative method based on in vitro culture demonstrated viability to obtain virus-free micro strawberry mother plants. Characteristics of strawberry mother plants obtained were superior in nutritional quality produced fruits. Additionally, the plants showed genetic stability and sanitary quality as they were virus-free.	Capocasa *et al.*, 2019

microbial collections (Khoury *et al.*, 2010; Mishra *et al.*, 2020; Sung and Hwang, 2017). The 809 microbial collections registered in the World Federation of Culture Collection (WFCC) facilitate the conservation of microbial genetic resources, at the same time, provide long-term reference material and play a key role in maintaining the balance of ecosystems (Pilling *et al.*, 2020); all these collections have microbial strains from all over the world. In Mexico, several universities, research centers and government and private institutions have different types of ceparium or microbial collections, but just 18 of them are registered in the WFCC. Among them: CDBB-Colección Nacional de Cepas Microbianas y Cultivos Celulares-CINVESTAV, CFQ- Cepario de la Facultad de Quimica, Universidad Nacional Autonoma de Mexico (UNAM), CM-CNRG-Colección de microorganismos del CNRG; COLMENA-Colección de microorganismos edáficos y endófitos nativos, Instituto Tecnológico de Sonora, and MCCBGHO-Banco de Germoplasma de hongos micorrizicos orquideoides, Departamento de Edafología, Instituto de Geologia, UNAM. All of them in charge of obtaining, preserving, classifying, studying, and documenting a collection of microbial cultures of specific interest, which generate a whole series of specialized information of relevance in different fields involved in human life.

The impact caused by the SARS-CoV-2 virus on the conservation of genetic resources in Mexico, as in other countries, has not been evaluated yet. To our knowledge, there is no evidence of the impact of the pandemic on the preservation of genetics resources globally (Neupane, 2020), but it is evident that the lack of economic sources for research focused on diversity and its conservation will have effects in the short, medium and long term (Bhandari *et al*., 2021; Wani *et al*., 2021). In addition, noting that the European Union's New Green Deal, focused on the post-covid recovery towards greener economies, has received support around the world and can help and lobby to generate greener economies around the world (Wani *et al*., 2021). Further investigations and approaches are likely to focus on legislation, regulation, and biodiversity management strategies to face future crises (Bang and Khadakkar, 2020); as proposed by an independent expert consultation commissioned by FAO, who propose that the global community related with genetic diversity research, should develop and implement a meso-level initiative (a scale of governance that connects macro and micro levels and includes the organizations, networks, and actors that work to accomplish tasks that further the collective goals) that includes a) the establishment of a new professional capacity to govern research and innovation at the meso-level, b) the global community should redouble efforts to build research capacity in genomic research and innovation in the global south and for indigenous people, and c) existing global policy frameworks interface with research governance and capacity investment (Welch *et al*., 2021).

Prospects for the agri-food sector in Mexico after the COVID-19 pandemic

The COVID-19 pandemic took the world by surprise and its duration even more. This crisis revealed the immense work that must be addressed at the global level to provide alternatives that improve the population supply of food and promote environmental, health, social, and economic resilience in the face of adverse natural events. Mexico is a center of agri-food biodiversity, a great exporter of agricultural products, and therefore responsible for the conservation of germplasm as world heritage and means of production. There is still much to do in Mexico to achieve biodiversity conservation. FAO (2020) in Response and Recovery Program, issue as principal suggestion adhering agricultural systems to the approaches that strengthen regional agriculture for health. In this context, possibly among the main challenges for the Mexican agri-food sector is to make its direct actors aware of the need to move towards environmentally and socially responsible food production, since, to a larger extent, agriculture in Mexico is seen as a source of income, and the predominant approach is still predominantly that of the exploitation of resources.

In Mexico, there have been advances towards the use of alternatives to conventional agricultural production methods. In response to the persistent occurrence of resistant pests and diseases, some farmers have chosen to incorporate biologically formulated products and some other sustainable technologies into their agricultural management schemes. Despite the need, Mexico still lacks the creation of a regulatory framework for the production and massive use of biological control agents, plant extracts, biosynthetic, and nanomaterials in the field. There have been some attempts in this area; progress on the generation of legal framework seems to advance at a much slower pace than the productive sector, which is currently using this type of products on a massive scale, without proper regulation.

Similarly, among the priority actions for the Government of Mexico is to continue promoting scientific research in the agri-food sector aimed at generating inventories of genetic resources associated with each zone, crop, animal, etc., e. g. the agreement: creating the Sectoral Committee on Genetic Resources for Food and Agriculture (DOF, 2020b). Is crucial to generate information on the agro-biotechnological potential of these genetic resources through the application of emerging technologies such as next-generation sequencing and analysis through the application of omics sciences. Agricultural Scientific Research Institutions in Mexico need to redirect their efforts to generate technologies and agricultural production methods focused on the use of local genetic resources that allow the country to approach food sovereignty and strength its resilience to health crises as has been developed in several countries (Table 1). Considering resilience as the dynamic process by which individuals, communities and societies positively adapt to significant adversity, resilient societies and economies are those capable of absorbing different types of crises; in this way, the national strategy needs to support economic survival and recovery in the COVID-19 context, considering the local demand and the possibility of local/regional production and distribution (Glonti *et al*., 2015; Dimian *et al*., 2021). Mexico has a great diversity of genetic resources with great potential to boost the agri-food sector; the country has qualified personnel and scientific research centers aimed at agricultural sciences distributed throughout the country. Strengthening and taking advantage of these would undoubtedly allow Mexico to adopt regionality and health approaches to rebuild a resilient agriculture post-COVID-19 pandemic.

CONCLUSIONS

The COVID-19 pandemic exacerbated that overpopulation and capitalism have directed agriculture to overexploitation of natural resources. In this way, current agriculture uses methods as massive monoculture production aided by agrochemicals. Additionally, the high degree of industrialization of food distorting its nutritional and nutraceutical qualities. Even when these methods go unnoticed and are taken daily, the effects of these production methods are evident; and is evident that the list of adverse effects that conventional agriculture has generated on our planet is far from sufficient. To mention a few, the atrophy of ecosystem services, loss of biodiversity, regional climate change, social polarization, hunger and poverty in vulnerable regions, and risks to human health as the current pandemic. Despite this, agriculture is the only means to generate food for humanity. The present COVID-19 pandemic is a call to restructure the Mexican, and the other countries, agricultural production system, by emphasizing the importance of agricultural products, using alternatives technologies and practices that generate a balanced diet and considering the importance of the role of agri-food genetic resources for agroecosystems balance and the need for their conservation.

The scenario seems fatalistic for humanity, and the pandemic made clear that there is no time to plan and prospect, it is time to take action to change the course. The means of production as water and soil, plant, livestock, fishery, forestry, invertebrate, and microbial genetic resources represent the pathway to guide agricultural production towards a sustainable production system based on ensuring environmental and human health. From the agricultural production systems based on genetic resources, it is possible to visualize the vindication of the agri-food sector in such a way that it is strengthened in functionality and in which one of the strengths is environmental, health, social, and economic resilience. Therefore, it is necessary to implement the nutrition-sensitive agriculture for health approach (Bahavani and Gopinath, 2020) and the regional and country approach (FAO, 2020). Thus, is important that the governments of each country provide the necessary legal and regulatory frameworks for the conservation and use of biodiversity. In this context, through the study, conservation, reproduction, and valuation of the biotechnological potential and responsible use of genetic resources, is possible to redirect agricultural production systems to resilience.

The current health crisis makes a strong call to the world, specifically to the ministries of agriculture, not only in Mexico but also in the governments of the world. It claims reflection, rethink, and redesign the agricultural production systems. Compromise the food chains to make available to the entire population and at affordable prices, fresh, nutritious food with nutraceutical properties, produced respecting the environment. Agricultural production systems based on the conservation and promotion of environmental and human health are a viable way to access food security. The strengthening of small producers and local food chains, using regional genetic resources and sustainable agriculture systems, promote local autonomy and consolidate small nuclei of sustainable production as units of resilience in the face of health crises such as that caused by the COVID-19 disease.

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