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# Haloculture: A system to mitigate the negative impacts of pandemics on the environment, society and economy, emphasizing COVID-19

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## ABSTRACT

COVID-19 (coronavirus disease) is a global pandemic that started in China in 2019 and has negatively affected all economic sectors of the world, including agriculture. However, according to estimates in different countries, agriculture has suffered less than other sectors such as construction, industry and tourism, so agricultural development can be a good option to compensate for the economic damage caused to other sectors. The quality of available water and soil resources for agricultural development is not only limited, but is also decreasing incrementally, so the use of saline and unconventional soil and water resources is inevitable. Biosaline agriculture or haloculture is a system in which highly saline water and soil resources are used sustainably for the economic production of agricultural crops. It seems that in the current situation of the world (with COVID-19's impact on agriculture on the one hand and the quantitative and qualitative decline of freshwater and soil on the other), haloculture with a re-reading of territorial capabilities has good potential to provide a part of human food supply. In this review article, the potential of haloculture to offset the adverse impacts of the pandemic is analyzed from five perspectives: increasing the area under cultivation, using unconventional water, stabilizing dust centers, increasing the body's immune resistance, and reducing losses in agribusiness due to the coronavirus. Overall, haloculture is an essential system, which COVID-19 has accelerated in the agricultural sector.

## 1. Introduction

The COVID-19 pandemic has caused havoc throughout the world (WHO, 2020). It is weighing on the global economy, and the recession is the most significant concern for governments around the world (Gray, 2020). The situation is particularly serious in less developed countries. Moreover, the economic crisis in these countries is severe since the economy is both stagnant and inflationary, with lower classes affected especially (Zhang et al., 2020). Due to instability in oil prices, particularly during the COVID-19 crisis, relying on oil is not a wise strategy and the focus will be on the non-oil sectors of the economy, which could have strongly negative repercussions on the subsistence of many communities. Nonetheless, there is a notable link between agricultural commodity and crude oil prices, as highlighted during the global financial crisis (GFC) in 2006–2008 (Baffes, 2007; Rosegrant et al.,

2008).

Although agricultural activities remained operational during the lockdown and US crude futures fell to negative values (Mensi et al., 2020), farmers and agri-entrepreneurs faced many difficulties in selling their fresh commodities at reasonable prices in local markets and most of the time they had to plow their fresh vegetables into the soil, instead of transporting them to markets.

As a result, the World Bank reported that exports of agricultural commodities have fallen by a considerable amount, with effects on the livelihoods of farmers and hence overall agribusinesses (Gray, 2020; Lal, 2020; Maliszewska et al., 2020). This information shows how the COVID-19 pandemic has further highlighted the current vulnerability of agriculture, already challenged by climate change and scarcity of resources, such as quantitative and qualitative reduction of water resources, salinization and infertility of soils, and global pollinator

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decline. It is believed that the temporal and spatial distribution and amount of precipitation as well as temperature patterns in different parts of the world have different effects, which cause the spatial and temporal distribution of water and soil resources to undergo different changes (Gao et al., 2017). It is estimated that doubling CO<sub>2</sub> concentrations by 2100 will lead to a 1–5 °C increase in temperature, which will result in significant changes in soil and water resources, energy, agribusiness, food production and forestry, and will intensify current environmental crises (Karimi et al., 2018). Globally, the effect of climate change on agricultural production has been negative but under-estimated until the middle of the century. The higher costs of practical actions to reduce the negative effects of climate change were associated with reduced production, especially for meat production and rice cultivation, which could be related to the intensity of greenhouse gas (GHG) emissions in the production process of these two products (Van Meijl et al., 2018). In general, GHG emissions are estimated by computer models considering different scenarios. In this research (Van Meijl et al., 2018), the intensity of GHG emission was estimated by five global climate and agro-economic models, consisted of integrated assessment (IMAGE), partial equilibrium (CAPRI, GLOBIOM, MAGPIE) and computable general equilibrium (MAGNET).

Developed countries were the main initiators of GHG and the climate change crisis. According to the UN Framework Convention on Climate Change, all countries in the world must take responsibility and take action to reduce the negative effects of climate change. Therefore, developed countries should take the lead in counteracting climate change and the negative effects of global warming, and help other countries (OECD, 2010). In this regard, developing countries and third world countries also play an important role. In general, to reduce the negative impact of climate change, developed countries can help themselves and developing countries from two perspectives: mitigation and adaptation. In the case of mitigation, developed countries fight climate change by reducing their own industrial activity and help to upgrade equipment in developing countries to reduce GHG. In the case of adaptation, some action should be taken to reduce the adverse consequences of climate change and to take advantage of positive opportunities (IPCC, 2007; OECD, 2010).

A variety of technical and moral supports have been extended to those affected. For example, remote consulting activities and teleworking in the technical sectors of agriculture have largely been provided, and electronic purchasing and posting of inputs have prospered to compensate the supply gap for agricultural products to some extent (Prasad and Mangipudi, 2020; Pu and Zhong, 2020). These supports also include the development of aquaculture, aquifer, mechanized rangelands, enrichment of aquatic water resources, and cultivation with new and efficient resources. Biosaline agriculture or haloculture is one of the practical approaches that could contribute to a reasonable extent to mitigating the COVID-19-induced adverse effects on food security and other ensuing socio-economic issues. Developing the agricultural sector with limited current resources at a lower cost, including through the use of haloculture, is also a way to offset the impacts of the coronavirus on unemployment.

On this basis, there is a need to reorganize the agricultural sector and provide it with increased capacity to maintain structure and functionality despite internal and external disturbances such as the pandemic. There are many available options to reduce and/or prevent the disruption in agriculture due to COVID-19, some of which are briefly listed in Table 1. These options are available depending on the local situations and the zone and/or community capacity.

Haloculture is an economic activity based on agriculture in saline soil using saline water resources. It is needed to develop new plants and new water management and includes all aspects mentioned in Table 1, which could help in preventing or mitigating the disturbances caused by the coronavirus. This study aims to provide an overview of the effects of COVID-19 and other epidemics on agribusiness and describes the benefits that haloculture can have in increasing the resilience of agriculture

**Table 1**

Solutions for reducing the effects of disturbances such as the pandemic on agriculture.

Solution	Affected section	Prerequisites	Reference
<b>Telecommunications and teleworking</b>	Transport/ Accommodation services/ Agricultural specialists and experts	Strong communication infrastructure/ Internet/ Smartphones/ Enough educated labor	(Okubo et al.)
<b>Artificial intelligence</b>	Agricultural specialists and experts/Lab services	Convenient tools/Enough educated labor	Eli-Chukwu (2019)
<b>Online Stores and internet retail</b>	Supply chain/ Transport	Internet/ Smartphones/ Enough educated labor	(Paunov and Planes-Satorra, 2019; Sharma et al., 2020)
<b>Processing industries</b>	Market/Supply chain/Transport	Convenient tools/Cheap and available technology/ Enough educated labor/ Financial support	(Compton et al., 2018; Sinha et al., 2012)
<b>Storing</b>	Market/Supply chain/Transport	Cheap and available technology/ Enough educated labor/ Financial support	Thompson (2008)
<b>Mechanization and automation</b>	Accommodation services/ agricultural specialists and experts/Labor	Cheap and available technology/ Financial support	Fadele et al. (2020)
<b>Intensive agriculture and aquaculture</b>	Transport/ Accommodation services/Food security/Labor market	Cheap and available technology/ Enough educated labor/ Financial support	Gephart et al. (2020)
<b>Natural resources (water, forest, and rangeland) enrichment and fertilization</b>	Transport/ Supply chain/ Food security/ Labor market	Cheap and available technology/ Financial support/ Specialists and experts	(Fox et al., 2007; Gupta et al., 2020; Snyman, 2002; Xu et al., 2020)
<b>New plants cultivation</b>	Transport/ Supply chain/ Food security/ Labor market	Cheap and available technology/ Financial support/ Specialists and experts/ Available land	Henry (2020)
<b>Development of water resource management</b>	Transport/Food security/Labor market	Cheap and available technology/ Financial support/ Specialists and experts/ Available land	Molden (2013)
<b>Haloculture/ Biosaline agriculture</b>	Transport/ Supply chain/ Food security/ Labor market	Cheap and available technology/ Financial support/ Specialists and experts/ Available land	(Khorsandi, 2016; Khorsandi et al., 2020)

in the face of disastrous events such as the recent pandemic.

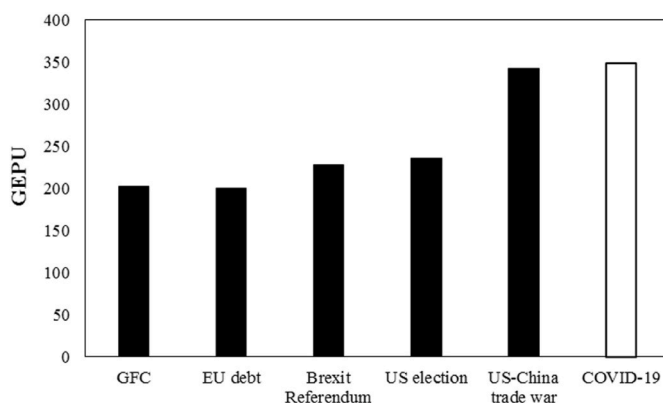
## 2. Methods

With the aim of considering and discussing all the aspects concerning haloculture, the PRISMA approach (Moher et al., 2010) was adopted to carry out bibliographic research. Databases including Scopus, Web of Science and Google Scholar were adopted and the research was carried out within the timeframe of 2000–2021. The search terms of “Haloculture”, “Saline agriculture” and “Biosaline agriculture” were used to develop the search strings. Only peer-reviewed journals and books were considered because they represent the best evidence of literature sources (Saunders et al., 2009). In a first step, only the title and abstract were reviewed to ensure the articles were relevant to the study scope. Afterwards, the C-I-M-O (context-intervention-mechanism-outcome) framework was adopted to guide the authors to deliberately select the most relevant articles (Briner and Denyer, 2012). Once articles were studied, other cited articles, relevant for the study, were added (i.e., snowball sampling).

## 3. Comparison of COVID-19 with the GFC and indicators

Comparing COVID-19 with previous crises can be useful in learning lessons for better management of the current crisis and preparation for future crises. When comparing the GFC in 2006–2008 with the COVID-19 outbreak, three major economic similarities are found: uncertainty, economic collapse and financial reactions (Strauss-Kahn, 2020). Of course, other similarities have been observed, such as widespread bankruptcies, unemployment, reduced liquidity, reduced purchasing ability, and so on (Tofighi, 2020). As soon as the GFC emerged in 2008 in the United States and COVID-19 in 2020 in China and then globally expanded, they showed uncertainty as an unavoidable risk. Based on an Atlantic Council report (Strauss-Kahn, 2020), two uncertainty indices, WPU (World Pandemic Uncertainty Index) and GEPU (Global Economic Policy Uncertainty Index) are now at their highest level. The GEPU and WPU stand at 348 and nearly 150 in the COVID-19 crisis, respectively, and are higher than those during the GFC (GEPU = 202, WPU = 10), as shown in Fig. 1. The economic collapse was clearly visible in both the GFC and COVID-19 crises. The initial decline in the stock markets of major countries was similar in the two crises, and interestingly, both global recessions have been recognized as the largest since the Great Recession between 2007 and 2009. To limit the negative impact of both crises, governments and organizations have provided broad support for monetary and fiscal policies.

Here are some examples of these fiscal protection policies in



**Fig. 1.** Global Economic Policy Uncertainty Index (GEPU) at various global crises (GFC: global financial crisis in 2006–2008, EU debt: European Sovereign Crisis in 2011, the Brexit Referendum June 2016, US election: US elections in November 2016, US-China trade war: the Trade War between the United States and China in mid-2019).

developed and developing countries during these two crises. As the most important governmental policies for financial support during the GFC crisis, governments and central banks of developed countries, including the Federal Reserve, the European Central Bank and the Bank of England provided unprecedented trillions of dollars as bailouts and stimulus. These broad fiscal policies provide banks with good resources to offset the decline in consumption and lending capacity, avoid a further collapse, encourage lending, restore faith in the integral commercial paper markets, avoid the risk of a deflationary spiral, and provide banks with enough funds to allow customers to make withdrawals (Fleming, 2012; French, 2009).

In 2020, it was announced that more than 10% of Iran's GDP would be used to improve the situation of patients and fight COVID-19. In the same year, Iran received a \$ 50 million loan from the World Bank to finance the import of drugs and medical equipment through the WHO. In late 2020, in response to an increase in new cases, the Iranian government unveiled another round of fiscal policies to support households, accounting for a total of 1% of GDP (IMF, 2021). The State Bank of Pakistan (SBP) has responded to the crisis by lowering policy rate by 625 basis points to 7.0%. The SBP has expanded the range of available investment facilities and introduced three new ones: 1) support hospitals and treatment centers to procurement COVID-19 related equipment, 2) stimulating investment in new factories and production machinery, as well as modernization and expansion of existing projects and 3) encourage business owners to prevent the dismissal of their workers during the COVID-19 outbreak (IMF, 2021).

In both the Great Depression and the GFC, unlike the current crisis, the main cause of the crisis was financial. Furthermore, the scope of geographical pervasiveness and human activities of the COVID-19 crisis is far greater than previous crises. In terms of casualties, there is a significant difference between these crises (Tofighi, 2020).

In the current crisis, in addition to economic supportive actions, extensive health measures have been taken. A variety of health measures are recommended by the World Health Organization (WHO), which have been adopted around the world, including in the United States, European countries, the Middle East, and the Far East. These sanitary measures include the following: curfew (prohibition of people movements in public spaces at certain times), lockdown (closing of restaurants, bars, gyms, and unnecessary stores to the public and opening essential stores with sanitary rules), teleworking of employees of government offices and private companies, virtual sales, limitations on public and private gatherings over a certain size, equipping the health system (adaptation of the organizations involved in the health system to guarantee health safety), measures in public transport (distance between seats, social distancing, controlling entrances, equipping stations and vehicles with disinfectants), obligation to wear a face mask in public places, increasing coronavirus testing, quarantine of patients, efforts to reduce urban and interurban commuting, supply of disinfectants, improving public health, etc. Most of these measures are being carried out in the large part of countries around the world (Palaniappan et al., 2020; Reshetnikov et al., 2020; Yang et al., 2020).

These security measures adopted during pandemics have impacts on energy security and food supply security which are the most important fundamentals for sustainable societies. During the COVID-19 pandemic, food supply security has been endangered by disruption in sectors such as agriculture, transport, accommodation services, specialists and experts, markets, supply chain, and the labor market, also indirectly energy security threatens food security by affecting all these sectors (Brosemer et al., 2020; Castán Broto and Kirshner, 2020; Jiang et al., 2021; Kim et al., 2020).

Regarding food security, there are many indicators for its measurement (Gil et al., 2019). For example, the Food and Agriculture Organization (FAO) mainly uses two indicators on hunger and food insecurity. These two indicators are the Prevalence of Undernourishment (PoU) and the Prevalence of Food Insecurity as measured through the Food Insecurity Experience Scale (FIES) (FAO, 2017). Regardless of the type of



index calculated, the result is always the same: disasters like pandemics harm food security and expand poverty (FAO, 2016, 2021) and this pandemic is no exception (Laborde et al., 2020).

The impacts of COVID-19 on agribusinesses were quantified and assessed using different methods such as questionnaire distributions, telephone interviews, data collection from societies and analysis (Lin and Zhang, 2020). For example, both FAO and WHO released data modeling and discussions (Mouloudj et al., 2020). Similarly, the national related departments, banks and governmental sectors proceeded through metadata collection and analysis (Barichello, 2020). Knowing that agribusiness disruption has a certain role in food insecurity, which is inevitable in the COVID-19 pandemic era, helps us to make proper plans to prevent future impacts on vulnerable people. Above all, despite energy consumption reduction (IEA, 2021), energy insecurity has an indirect undeniable role by rising energy prices (Graff and Carley, 2020).

With all these interpretations, the differences between the current crisis and the 2006-08 GFC are greater than the similarities, however, the lessons learned from these crises can be the same. Sustainability of systems, dynamic economy, virtual commerce, revision of development models for systems variability, correction of risk assessment, targeted financial support, health and medical advances, reducing reliance on fossil fuels, supporting startups and start-up knowledge-based companies can help prevent economic shocks caused by crises in the future.

#### 4. COVID-19-induced agriculture vulnerability

The COVID-19 pandemic is causing more negative repercussions than the global financial crisis in 2006–2008 or even the 2002-03 SARS-CoV-1 epidemic (Mensi et al., 2020). Agriculture, like any other economic sector, has suffered greatly due to the coronavirus. A summary of its effects on various aspects of agriculture in different countries of the world are shown in Table 2.

The effects of COVID-19 on agriculture have aggravated the risks of extreme food insecurity. Indeed, with the onset of COVID-19, an additional 130 million people could be pushed into starvation by the end of 2020, bringing the total to 265 million (Lal, 2020). This information, reported in Table 2, confirms that epidemics and the sanitary measures necessary to mitigate their spread may have a negative impact on agriculture, as has already happened in the recent past with other epidemics (Table 3).

The FAO has also warned that the coronavirus has significant

**Table 2**

The effects of COVID-19 on various aspects of agriculture in different countries of the world.

Country	Effects on agriculture	Reference
USA	Decline in the agriculture sectors by 4%	Maliszewska et al. (2020)
Canada	10%, 8% and 15% fall in corn, soybean and livestock prices respectively	Barichello (2020)
China	Decrease in GDP of the agriculture and food system by 7%, unemployment of 46 million agricultural workers	Zhang et al. (2020)
Iran	31% decrease in imports of agricultural products, 5% reduction in livestock production, 35% increase in price of fruits and nuts and economic losses of 500 million USD	Sheikhi et al. (2020)
India	Rice and wheat production decrease of about 24% and economic losses totaling 1.5 billion USD	Shirsath et al. (2020)
Myanmar	A 14% fall in gross domestic product (GDP) of agriculture	Diao & Wang (2020)
Ethiopia	A decline in coffee trade compared to 2019 and 2018 of 32% and 26% respectively	Tamru et al. (2020)
European countries	Decrease in GDP of agriculture and natural resources of 3% and 1%, respectively	Maliszewska et al. (2020)

**Table 3**

The effects of previous pandemics on agriculture.

Region	Pandemic	Effects	Reference
West Africa	Ebola	12% reduction in production of staple crops	Huber et al. (2018)
Liberia	Ebola	A 54% reduction in agricultural production	Gatso et al. (2018)
Liberia	Ebola	15% of food and beverages sector closed down	Bowles et al. (2016)
China	SARS	9% losses in agricultural sectors	Ceylan & Ozkan (2020)
South Korea	SARS	11% losses in agricultural sectors	Ceylan & Ozkan (2020)
Saudi Arabia	MERS	Infection of 85% of camels, 16% reduction in the real per capita GDP	Faridi (2018)
Western Europe	Avian influenza	Up to 1% losses in agricultural sectors	Keogh-Brown et al. (2010)

negative effects on everyone involved throughout the food supply chain, affecting food security, and food and agricultural systems. This loss has not directly affected food and agriculture, but has reduced production and/or has caused producer losses by reducing and/or disrupting the supply of resources, manpower, and agricultural inputs (Schmidhuber et al., 2020).

Nevertheless, according to reports in different countries of the world, it can be concluded that the impact of COVID-19 on agriculture has been lower than other economic sectors such as tourism, industry, and construction (Diao and Wang, 2020; Maliszewska et al., 2020; Zhang et al., 2020). Diao and Wang (Diao and Wang, 2020) estimated the declines in GDP due to COVID-19 in the construction, services, industry, manufacturing and agriculture sectors in Myanmar at 82%, 56%, 52%, 40% and 14%, respectively. Zhang et al. (2020) estimated that under the influence of COVID-19, China's GDP fell 6.8% in the first quarter of 2020 compared to 2019, while the agri-food system's economic loss equaled 7% of its value added. As China's economy recovered in the second and third quarters of 2020, the growth rate of the value-added agri-food system increased, but remained moderate. Despite the lesser impact of the coronavirus on agriculture, employment is improving more slowly in the agri-food system than in other sectors, due to the slow recovery of restaurants (Zhang et al., 2020). This was also reported on a global scale. Thus, COVID-19 has led to a sharper decline in services and other sectors compared to agriculture. The most negative shock due to COVID-19 was observed in the output of domestic and tourism services. Globally, the output of services, tourism and agriculture has decreased by about 9.3%, 8.8% and 3%, respectively as affected by COVID-19 (Maliszewska et al., 2020).

Economic decline in domestic services (% deviations from the benchmark), tourism and agriculture in European countries (including Italy) was 9.04, 9.06 and 3.00, respectively, in the Middle East (including Iran) was 8.04, 9.28 and 2.62, respectively and in South Asian countries (including Pakistan) was 9.11, 10.03 and 2.76, respectively (Maliszewska et al., 2020). In Italy, as one of the most important tourist destinations in the world, tourism revenue fell from 24.5 million euros in 2019 to 15.6 million euros at best and 7.2 million euros at worst (Statista, 2021). Tourism in Iran has also been severely damaged by the COVID-19; so that the number of tourists in 2020 compared to 2019 has decreased by about 90%. Tourism revenue of Mashhad, as one of the most important tourist cities in Iran with about 35 million tourists annually, has decreased by 80% due to the COVID-19. Therefore, investing in new agriculture strategies could be a good opportunity to offset some of the economic downturn caused by the coronavirus in other sectors.

#### 5. Vulnerable people in the COVID-19 era

Although there is enough food to feed everyone in the world, the

prevalence of COVID-19 could severely disrupt vital food supply chains both within and among countries. According to a report (Schmidhuber et al., 2020), imposition of limitations on exports and imports may cause intricacy for food transportation to markets and food processing units. Under these circumstances, the effects of this disruption could be experienced by both producers and consumers, thereby causing a decrease in farmers' incomes. Moreover, food prices could become highly volatile and people may experience food shortages. This situation is likely to have significant negative effects, especially on vulnerable groups, such as informal workers, vulnerable urban populations, and others who rely heavily on the local market to meet their food needs (Zhang et al., 2020). Reducing or losing revenue along with volatile prices can have serious implications for the acute food security situation and malnutrition levels of these populations.

The combination of the above effects could potentially lead vulnerable households to adopt some mechanisms that will have a lasting impact on their lives and livelihoods, such as reducing the number of meals, increasing dropout rates, reducing the facilities available to cover health and medical expenses, sales of production tools, etc.

The impact of climate change on agribusiness is more severe in subsistence farming, small-scale production units and poor families in underdeveloped local communities. Although financial incentive approaches can lead to short-term gains, they increase the vulnerability of these communities in the long run (Karimi et al., 2018). In Nepal, for example, COVID-19 has severely pressured subsistence agriculture and small-scale farmers in underdeveloped societies that depend on agriculture and also ensure Nepal's food security. Even after overcoming coronavirus, if agricultural patterns in such communities are not improved and continue to be disrupted, millions of people will lose their livelihoods and the country's food security could be threatened. Therefore, extensive measures should be considered to minimize the damage to subsistence agriculture in the short-term and to plan for the creation of more resilient communities in the long-term. Possible practical solutions include "global supply of agricultural products through central sales units to the market", "returning the staple crops to the track" and "reducing the pressures on the land to increase production" (Deuja, 2020).

In the local agricultural communities of Iran, food security assessed via adequate food supply, sustaining food supply and food availability has also encountered problems due to COVID-19. The majority of people in these communities are low-income and poor people, whose access to food has drastically decreased with the outbreak of COVID-19, which requires the government to support all vulnerable groups in an expert and accurate program. The majority of Iran's agricultural producers are small-scale farmers whose job security and income have been compromised by COVID-19 (Zarafshani et al., 2020). In Myanmar, the highest decline in income was related to female-headed households (about 20%) and the lowest decline was related to urbanites at about 5%). Farmers also saw a significant drop in income at about 16% (Diao and Wang, 2020). It has been revealed that COVID-19 has caused the unemployment of 46 million agricultural workers in China, and the unemployment crisis has been greater among the unskilled than among skilled laborers (Zhang et al., 2020).

Pandemics have the greatest impact on people with the lowest income in societies. In economies that have affiliations with capitalism and free trade, these groups of people are more affected. In fact, in these communities, social help services depend on their incomes, which directly target their food security and making them vulnerable to hunger crises (Ahmed et al., 2020; Jay et al., 2020; Nagarkar, 2020). Lack of insurance capabilities and no supporting law for low-income people forces them to choose a limited diet. On the other hand, in communities which provide good social help services, vulnerable people with low incomes are able to meet their vital needs, including enough food. In contrast, people of all income brackets are pressured by pandemics in underdeveloped societies, if the government has no special program (Ahmed et al., 2020; Jay et al., 2020; Nagarkar, 2020).

COVID-19 targets all income sectors, but high-income people are affected less than people on low incomes. High-income households have access to better medical support and medicine and are able to tolerate more food distribution disruption, so achieve better well-being levels. Refugees may be the most vulnerable among low-income people around the world and face all aspects of COVID-19 challenges, specifically, unemployment and insufficient food (Farr, 2020). Climate refugees from Africa, Afghanistan, war refugees from Afghanistan, Iraq, and Syria, and economic migrants from Pakistan, Iran, and Italy change their living location to achieve a higher life standard. Iran (with more than 2.5 million refugees) and Pakistan (about 1.4 million) have had a high number of war migrants/refugees from Afghanistan, Iraq, and Syria for decades, which are struggling with food insecurity. In addition, nowadays, Europe, especially Italy (estimated near 500,000) are facing the challenge of climate migration, with migrants originating from the MENA region (Hartmann, 2010; Malik et al., 2019; Naseh et al., 2018; Podesta, 2019) in need of social help to access proper food and medicine.

The host countries are less able to help migrants with all their demands compared to before the COVID-19 era. The countries and NGOs active in the humanitarian situation are not capable of supporting and helping them anymore due to the economic situation caused by the pandemic. Therefore, COVID-19 endangers the health and food security of migrants and refugees, but also threatens their life by weakening support services in host countries.

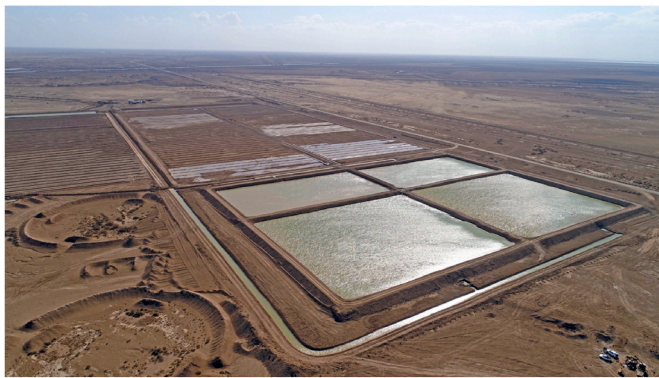
## 6. Biosaline agriculture/Haloculture

Although there are several definitions for biosaline agriculture (Abdelly et al., 2008), recently (Ayyam et al., 2019), have defined biosaline agriculture as "the plant-based approaches of using salt-affected land and water based on the salinity ranges of soil, water, and other associated factors". A little earlier (Nikalje et al., 2018), indicated that biosaline agriculture is "profitable and improved agricultural practices using saline land and saline irrigation water with the purpose of achieving better production through a sustainable and integrated use of genetic resources (plants, animals, fish, insects, and microorganisms) avoiding expensive soil recovery measures". Before these two definitions (Ladeiro, 2012), had said "an innovative strategy for enhancing land and water availability is the use of salted soils and salted water, in a strategy designated as saline agriculture." In general, we can summarize haloculture as "sustainable and economic utilization of saline water and soil resources".

Haloculture, in addition to avoiding land degradation, makes it possible to carry out commercial activities in marginal lands (Abdelly et al., 2008). These activities could be production of forage, wood, medicinal plants, edible and oily seeds, vegetables, and bio-mass/bioenergy or poultry/livestock rearing (Ayyam et al., 2019; Khan and Ansari, 2008; Pirasteh-Anosheh et al., 2016). Furthermore, it has been demonstrated that the adoption of haloculture improves the characteristics of a soil, reducing the soil salinity and making sustainable use of unconventional water (Abdelly et al., 2006; Duarte and Caçador, 2021; Qureshi et al., 2018). A sample of a haloculture complex in the southwest of Iran is shown in Fig. 2. The haloculture approach has three main purposes: water reuse through irrigation with wastewater, degraded/salinized land exploitation, and produce higher value-added products (Ashraf et al., 2006; Nikalje et al., 2018). On this basis, it is possible to state the most important aims of haloculture are (Al-Attar, 2002):

- production of more food and creation of more sustainable livelihoods per unit of water applied
- better management of human water and soil use to conserve the quantity and quality of freshwater and terrestrial ecosystems that provide services to humans and all living things

We believe that the "diversification of agricultural products for the promotion of food security" is the most important aim of haloculture,



**Fig. 2.** A sample of a haloculture complex. This is a haloculture research pilot that has been established in Jofair region, Khuzestan Province, in the southwest of Iran, in a joint program between the “National Salinity Research Center, Agricultural Research, Education and Extension Organization” and “Biotechnology Development Council, Vice-Presidency for Science and Technology”. This 50- hectare research pilot has 40 ha of cultivated area including 5 ha of fishery, 20 ha of arboriculture and 15 ha of farmed crops.

however, diversification of the land and water source use can also be an important aim.

Haloculture refers to all economic activities related to agriculture in very saline soils and water conditions (Pirasteh-Anosheh et al., 2016). In other words, haloculture means agriculture with saline water in saline land - an unconventional agriculture. Haloculture operates in hyper-saline and saline lands, in which conventional farming is no longer economical or feasible. Therefore, it is not a competitor for common agriculture, but can be a suitable supplement (Khorsandi et al., 2020; Yensen, 2002).

The policies of different countries of the world towards reclaiming the land for the exploitation of very salty resources, although differing in detail, follow the same approach in general (Khorsandi, 2017). Of course, most policies are in the form of research, extension and development pilot programs, and there is no real implementation plan. As an example, we can mention various research-extension institutes that are active in the field of haloculture. These include the Halophyte Biotechnology Center at the University of Delaware, the International Center for Biosaline Agriculture in Dubai, United Arab Emirates, the Institute of Sustainable Halophyte Utilization at the University of Karachi, Pakistan, the National Salinity Research Center in Yazd, Iran, the Organization for Agriculture in Saline Environments in the Netherlands, and The Seawater Foundation in various countries around the world. Indeed, rereading territorial capabilities for major economic products have only been carried out in the last two cases. The Seawater Foundation had two major projects: the production of shrimp, salicornia, and mangrove in Eritrea in 1998, and the production of salicornia, shrimp, and mangrove in Mexico in 2010. Also in Mexico, the Organization for Agriculture in Saline Environments is engaged in agro-forestry for wood production, salicornia cultivation and seaweed harvesting (Khorsandi, 2017; Khorsandi et al., 2020; Pirasteh-Anosheh, 2020). Some other agricultural production of haloculture systems are listed in Table 4.

## 7. Haloculture capabilities to counteract the adverse effects of COVID-19

COVID-19 affects food security in many ways: availability, access, utilization, and stability. Although major agricultural activities were not directly restricted, the researchers found that due to falling demand from other sectors, lower exports, decreasing consumer demand linked to declining incomes, and health problems for agricultural workers, COVID-19 had significant indirect effects on agribusiness (Diao and Wang, 2020; Maliszewska et al., 2020; Zhang et al., 2020). Just as the pandemic has indirectly affected agricultural production and the food

**Table 4**

Some agricultural products of haloculture systems in different regions of world.

Region	Aim	Species	Reference
Turkey	Grain	<i>Chenopodium quinoa</i>	Yazar et al. (2015)
USA	Oil seed	<i>Salicornia bigelovii</i>	Glenn et al. (2013)
Iran	Vegetable	<i>Salicornia</i> spp.	Ranjbar & Pirasteh-Anosheh (2019)
Poland	Wood	<i>Alnus glutinosa</i>	Deptuła et al. (2020)
Bangladesh	Wood	Mangrove species	Rahman et al. (2020)
Iran	Medicinal	<i>Cynara scolymus</i>	Daghaghian et al. (2017)
Pakistan	Forage	<i>Sporobolus arabicus</i> , <i>Leptochloa fusca</i> , <i>Panicum turgidum</i>	Ahmad & Ismail (2002)
USA	Forage	<i>Atriplex lentiformis</i>	Glenn et al. (2013)
USA	Forage	<i>Atriplex</i> spp.	Mata-González et al. (2017)
Romania	Forage	<i>Agropyron tenerum</i> , <i>Agropyron elongatum</i> , <i>Sorghum</i> “Chihlimbar”	Grigore & Cojocariu (2020)
Egypt	Forage	<i>Leptochloa fusca</i> , <i>Spartina patens</i> , <i>Sporobolus virginicus</i> & <i>S. virginicus</i>	Ashour et al. (1997)
Australia	Forage	legumes and grasses	Masters et al. (2007)
Australia	Livestock	Sheep & cattle	Masters et al. (2007)
Bangladesh	Aquaculture	Shrimp costal silvo-aquaculture	Rahman et al. (2020)

supply process (Laborde et al., 2020), haloculture can also indirectly affect the disease and offset some of the negative effects. The following strategies can be considered as haloculture capabilities to counterbalance the negative effects of COVID-19. The extent to which each of these capabilities can potentially be realized needs further investigation. These capabilities and their relationship are illustrated in Fig. 3 and in graphical abstract.

### 7.1. Increasing the cultivation area

Twelve percent (about 1.6 billion ha of world land) of the total global land area is cultivated for producing agricultural crops, rising to 20% of available lands in low-income countries (FAO, 2011). As mentioned above, COVID-19 has a significant negative impact on the production and transfer of commodities. To increase production in this situation, haloculture systems can be introduced in saline lands, which are almost unusable in conventional agriculture (Shabbir, 2013; Toderich et al., 2008). The land, in fact, is contemplated as a life-perpetuating stage for food and water (Nikalje et al., 2018). Good quality soils already have agricultural uses and there is rising competition between agriculture and other economic sectors, which has left few spaces of high quality land for agricultural extension (Khorsandi, 2016). The world's salt-affected lands are about 50% of irrigated areas. Furthermore, as a consequence of salinization in these lands, more than \$12 billion economic losses have been estimated in the agricultural sector (Shabala, 2013). There is very little arable land left, and even if any remains, the critical limited freshwater resources do not allow for the development of conventional agriculture. Therefore, there is no choice but to use saline and hyper-saline land to develop agriculture and increase production, so as to reduce some of the COVID-19-induced production declines.

### 7.2. Utilization of unconventional water

To compensate for the decline in production due to the prevalence of COVID-19, unconventional water sources such as saline surface water and groundwater, saline well water, sewage water, farm drainage, seawater, and saline lakes can enter the production cycle. Good research has been done in this regard and the technical knowledge of many products has been prepared (Duarte and Caçador, 2021; Toderich et al., 2008). In a haloculture system, halophytes are the most important



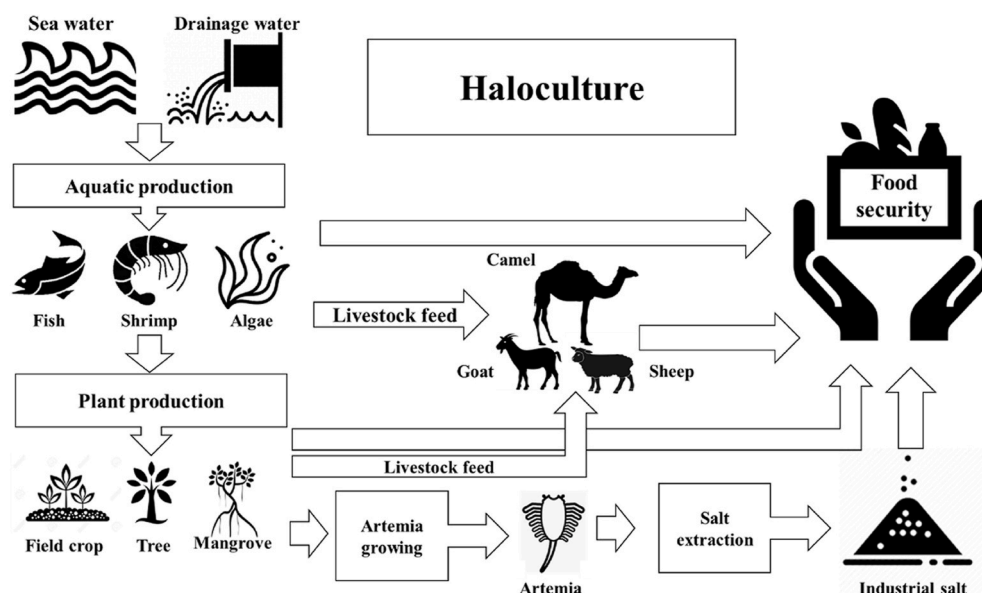


Fig. 3. The process of using unconventional water in a salinity system with its components in order to achieve food security.

component, which we defined as “plants with the ability to adapt in saline conditions through preventing salt from entering the plant or reducing the salt concentration in the cytoplasm”. Halophytes can grow with unconventional water sources that are not appropriate for conventional crops and are particularly meant for producing fuel, food, fodder, oils, fiber, plant resins, essential oils, and medicinal plants (Khan and Ansari, 2008; Ladeiro, 2012; Shabbir, 2013).

### 7.3. Stabilization of airborne dust centers

Dust air pollution affects an area of more than 1.4 million square km and over 800 million people in the world (Wu et al., 2016). Most of these people live in developing countries experiencing the detrimental effects of COVID-19 (Loayza, 2020). Haloculture has a good potential to generate vegetation and reduce wind and water erosion, and thus can stabilize airborne dust centers. Agricultural production in saline conditions requires more leaching to control the salinity of the root zone; in addition to increasing the entry of salts into the deeper soil layers, this also causes more soil erosion, leading to the production of dust. Cultivating halophytes in haloculture systems reduces the need for water and the need for leaching. This is especially important in areas such as the Middle East, where dust and drainage are a pervasive crisis. The important point is that in the most significant centers of fine dust production, the COVID-19 situation is in a critical state. It is believed that the coronavirus can spread by airborne dust particles (Qu et al., 2020). Scientists believe that some diseases could spread through the population by airborne pathogen transmission. Some developing countries are struggling with air pollution, since dust particles may transmit COVID-19 and accelerate the infection rate (Qu et al., 2020). Notably, it has been stated that soil particles can contain microorganisms such as the coronavirus, and this is exacerbated when sewage sludge enters the soil (Conde-Cid et al., 2020; Núñez-Delgado, 2020). Therefore, haloculture reduces the production of fine dust and stabilizes the centers of fine dust by creating vegetation and reducing erosion (wind and water), which in turn can reduce the prevalence of COVID-19 and other pathogenic microorganisms proliferated in saline soils. Indeed, in addition to the coronavirus, there are some other pathogens that can be spread by saline and/or sodic soil particles, some examples of which are listed in Table 5.

There are many airborne dust centers around the world. These centers appear after land degradation, which may relate to human activities. The most important factors in shaping dust centers are lack of

Table 5  
Some pathogens transmitted by dust storms.

Pathogen transmitted	Originated zone	Affected zone	Reference
<i>Bacillus</i> species and fungi related to asthma	African Sahara	Barbados	Blades et al. (1998)
Meningitis spores	Sahara	Spain, Italy and Greece	Vidal & John (2009)
Ambient influenza (A and A/H5)	Mongolia & China	Taiwan	Chen et al. (2010)
Viruses, bacteria and fungi associated with respiratory diseases	Arabian Desert	Saudi Arabia & Pakistan	Meo et al. (2013)
Ambient influenza	China	China	Chen et al. (2017)
Enterovirus	North Africa	Spain	Gonzalez-Martin et al. (2018)
<i>Acanthamoeba</i> spp.	Syria and Iraq	Iran	Saberi et al. (2019)
<i>Salmonella</i> spp.	Iran	Iran	Soltan Dallal et al. (2020)

water, soil salinization, low vegetation cover, and high-speed winds (Al-Hemoud et al., 2019; Middleton, 2017). As mentioned, meteorological conditions especially precipitation and wind speed are the key to the formation of airborne dust centers. North Africa (the Great Sahara region), Pakistan, India, China, Syria, Iran, Iraq, Persian Gulf region countries, etc. Are affected by wind erosion and face the consequences of airborne dust centers (Manisalidis et al., 2020; Middleton, 2017). Airborne dust is one of the most important causes of air pollution in the mentioned areas (Miri et al., 2009).

### 7.4. Increasing the body's immunity by producing medicinal halophytes

Most halophytes mentioned for haloculture systems are of a medicinal nature, and many others, although not known as medicinal plants, have considerable medicinal effects. For example, *Myracrodruon urundeuva*, *Aspidosperma pyrifolium*, *Erythrina velutina* and other halophytes of Caatinga bioma are used by the population of Sertão region (Brazil) to cure some ailments (Dantas et al., 2014). In order to acquire adaptation and normal growth and development, halophytes synthesize some special biochemical compounds and secondary metabolites (Boestfleisch and Papenbrock, 2017). These varieties of molecules and biochemical compounds include steroids, flavonoids, alkaloids, phenolics, tannins,



glucosides, terpenoids, coumarin, nitrate, oxalate, amino acids, carotenoids, and some other organic acids, etc. (Nikalje et al., 2018). Most of these compounds effectively act as antioxidants to scavenge stress-induced reactive oxygen species (ROS), which can prevent cell mutation, ageing and many diseases if added to the human diet (Slama et al., 2015). There are more than 6.5 million hectares of salt-affected land in the world and about 2 million hectares are low/moderately affected (Qasim et al., 2011). Also, 45 halophytes are introduced as medicinal plants which could be cultivated in coastal areas (Qasim et al., 2011) and more of them named as medicinal halophytes (Ksouri et al., 2012).

Above all, cultivation of medicinal halophytes that strengthen the immune system in haloculture systems and its consumption with medical considerations, can reduce some of the negative effects of COVID-19. For example, Khaerunnisa et al. (2020) surveyed some compounds in medicinal plants and recommended kaempferol, quercetin, luteolin-7-glucoside, apigenin-7-glucoside, naringenin, oleuropein, demethoxycurcumin, curcumin, catechin, and epigallocatechin as potential inhibitors of COVID-19. These compounds are found in various plant species including spinach (*Spinacia oleracea*), dill (*Anethum graveolens*), olive (*Olea europaea*), turmeric (*Curcuma longa*), tea plant (*Camellia sinensis*) and ginger (*Zingiber officinale*). Some plants such as licorice (*Glycyrrhiza glabra*), mangrove (*Avicennia marina*), pomegranate (*Punica granatum*), pistachio (*Pistacia vera*) and ginger (*Zingiber officinale*), have varied levels of salinity tolerance. Most of these plants, with high salinity tolerance can grow in saline agroecosystems. Licorice is a plant that easily grows and reproduces as a native species in saline environments. Pomegranates and especially pistachios, are trees that are cultivated in saline soils using saline water in many areas, and mangrove is a tree that grows naturally in very salty water (more than 40 dS m<sup>-1</sup>) off the coast (Pirasteh-Anosheh, 2020; Pirasteh-Anosheh et al., 2016).

These species with high salinity tolerance have the ability to increase the body's immunity. For example, glycyrrhizin, glycyrrhetic acid, liquiritin and isoliquiritin in licorice counter the activity of COVID-19 and could be used as an antiviral drug (Chowdhury et al., 2020). Also, antiviral nano-membrane could be made from licorice to produce wound-dressing materials, masks, gloves and skin infection drugs (Khanna et al., 2020). There are many medicinal forms of licorice (e.g. licorice root syrup, glycyrrhizin capsule, licorice root capsule, licophar and so on) and ginger (e.g. ginger pill, ginger dragees, Zoe ginger capsule, vemigan, gino BZ, and ...) on the market. Pomegranates and pistachios, although commonly consumed as fruits, sometimes have their medicinal forms (e.g. Hematogol, Pomega, Anar, and ...) available on the market.

The side effects, high prices and environmental pollution of chemical drugs could encourage the international community to provide medicinal plant-based clinical products such as alcohol, masks, sanitizers, soap, etc. For counteracting the coronavirus.

#### 7.5. Reducing losses in agribusiness due to COVID-19

Both haloculture and conventional agriculture entail costs related to manpower and chemical and non-chemical inputs. However, haloculture can be performed with cheaper land and water sources (Abdelly et al., 2008). Haloculture can boost agricultural production with the underused resources of saline soil and saline water in seemingly barren lands, which can be set up with resources of about 10% of the cost in normal agricultural conditions (Khorsandi, 2016). This means the production of, for example, livestock fodder in a haloculture system is more economical than its production through conventional agriculture (Khorsandi et al., 2020). This already favors haloculture in normal conditions, but in conjunction with catastrophic events destroying farming or causing damage to agricultural trade, haloculture has a very important advantage: it reduces losses. It can therefore be argued that haloculture is more ecofriendly and cheaper than conventional agriculture. Consequently, when a crop is damaged due to a pandemic, such

as COVID-19 or something similar that may happen in the future, the losses are fewer in agriculture, in both economic and environmental aspects.

## 8. Conclusions and future perspectives

The service and trade sectors have suffered the most from COVID-19, while agriculture and natural resources have experienced the least impact, and this could be viewed as an opportunity. With the expansion of large online companies and chain stores, the role of technology is increasing and services are declining. As the coronavirus accelerates the shrinkage in the trade and services sector, the need for energy has decreased and economies are moving towards independence to increase capital security. The global economy is changing as a result of this behavior, from business-oil to agriculture-gas. Limited freshwater has increased the need to use unconventional resources such as saline water and soil in order to ensure food security for the rising world population. Therefore, adopting haloculture is desirable, since it is doubly important in the current situation. Indeed, as well as having a lower impact on the environment and making little-used resources available to agriculture, haloculture can benefit the fight against the COVID-19 pandemic and counteract its induced negative effects.

Due to the increasing trend of saline soils and declining water quality along with a quantitative decrease in freshwater resources, more attention will be paid to haloculture. Covid-19 has not created the haloculture system, however, it has accelerated the move towards it. Therefore, it seems that in the future haloculture will be of more interest to plant scientists (due to plant diversification), investors (due to high economic productivity) and environmentalists (due to sustainability). In this regard, the role of haloculture in reducing the negative effects of climate change and heat islands should be given more attention. The physiological and molecular aspects of the tolerance and survival mechanisms of halophytes under hyper-saline conditions should be studied. Also, the economic, social, political and environmental factors of haloculture systems have not yet received the necessary attention. In general, haloculture is expected to play a greater role in the future of the world.

## Credit author statement

Hadi Pirasteh-Anosheh: Conceptualization, Methodology, Project administrator, Writing – original draft, Writing – review & editing. Amir Parnian: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. Danilo Spasiano: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. Marco Race: Writing – review & editing, Supervision, Project administrator. Muhammad Ashraf: Supervision, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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