Agricultural Systems 191 (2021) 103134

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

The two-way relationship between food systems and the COVID19 pandemic: causes and consequences

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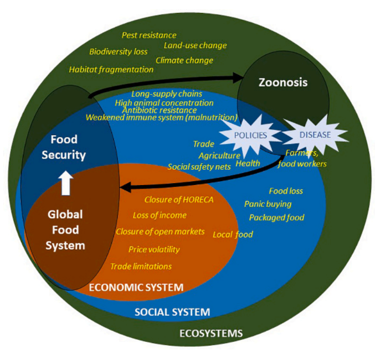
HIGHLIGHTS

- Food systems have a twofold relation with COVID-19: as a facilitator of the virus outbreak, and as being impacted by the pandemic.
- Industrial food systems are a driving factor in emergent infectious diseases due, inter alia, to their contribution to land use changes and habitat fragmentation.
- Food supply chains and food security have been negatively impacted by COVID-19.
- Industrial food systems are highly vulnerable to global crises and shocks, such as COVID-19, due to their low resilience and flexibility.
- COVID-19 can be an opportunity to assess vulnerabilities and speed up the transformation of food systems.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Emma Stephens

Keywords:
Zoonosis
Social-ecological resilience
Industrial farming
Food security
Food systems
Emerging infectious diseases
Agroecology
Short food supply chains

ABSTRACT

CONTEXT: The COVID-19 pandemic has become one of the most pressing challenges for humanity. The pandemic is affecting all aspects of human lives and livelihoods, including food. In this context, new research shows the nexus between agri-food systems and the spread of emergent infectious diseases (EID) such as the coronavirus disease while at the same time, shows how the COVID-19 pandemics has heavily impacted food systems.
OBJECTIVE: The aim of this work is to shed light and draw, through the case of COVID-19, the network of direct and indirect links and feedback loops between the globalised food system and pandemics.
METHODS: We conducted a literature review.
RESULTS AND CONCLUSIONS: As with climate change, food systems have a double relation with EID in general, and in particular with the present world health crisis linked to COVID-19. On the one hand, global agri-food systems, as currently organised, are a necessary step in the development of EID, through their impacts in land use changes, habitat fragmentation, biodiversity loss and climate change. On the other hand, COVID-19 has had

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https://doi.org/10.1016/j.agsy.2021.103134
Received 20 October 2020; Received in revised form 12 February 2021; Accepted 16 March 2021
Available online 23 March 2021

and is having impacts on all food systems at all scales. The review shows that all activities of the food system (from production to consumption) as well as all pillars of food security (availability, access, use, stability) have been affected. The impacts of COVID-19 pandemic on food systems can be divided between direct impacts of the virus outbreak, and indirect impacts derived from the containment measures (e.g. lockdowns, mobility restrictions, shops closure) adopted at different levels (from local to global). While all food systems across the globe have been affected by the pandemic, it is argued that vulnerability is different for different types of food systems. Long food supply chains have been particularly affected by COVID-19 crisis, however, it is important to avoid universalization of impacts and responses as agri-food systems are characterised by a huge diversity and heterogeneity. The review concludes by pointing out that while the pandemic represents a challenge for the global food systems, this 'stress test' can be also seized as an opportunity to highlight vulnerabilities to be urgently addressed during the recovery period and speed up the transformation towards more sustainable and resilient food systems.

SIGNIFICANCE: A food systems approach is essential to have a broader picture of the relationship of agri-food systems with zoonosis and their centrality in the pandemics and the derived socio-economic consequences.

1. Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) causing COVID-19, also known as coronavirus disease, has created a completely novel situation worldwide. With more than two million deaths and 104 million infected (as at 2nd February 2021) (WHO, 2020), COVID-19 is the biggest pandemics in the last few decades and definitely the one with the highest socio-economic impacts worldwide - and the situation is still characterised by a high degree of uncertainty (HLPE, 2020). As the pandemic spread around the world in early 2020, countries went into lockdown with only essential economic sectors remaining open (among which agriculture and food related ones) and most people confined to their homes (United Nations, 2020a). As a consequence, transportation of people and goods was drastically reduced, supply chains disrupted, businesses closed, the stock market collapsed, and unemployment boosted (Nicola et al., 2020). The exponentially growing pandemic has gone hand in hand with an exponentially growing worldwide economic crisis (Gunther, 2020; IMF, 2020; Maliszewska et al., 2020; United Nations, 2020a). According to FAO et al. (2020), an additional 83 to 132 million people can be added to the 690 millions of people undernourished in 2020 due to the economic consequences of the COVID-19 pandemic. In this context, it is our objective to shed light on the centrality that food systems have in the much needed reflections about COVID-19 pandemic, both due to the role they played in the growth of emergent infectious diseases (EID) in general (of which COVID-19 is an example), but also in how food systems and food security have been directly and indirectly impacted by the COVID-19 pandemic. To achieve this objective we have performed a literature review (Grant and Booth, 2009) of both academic as well as and non-academic and press articles using the search engines "scholar google" and "google.com".

COVID-19 is a zoonosis, that is, a disease or infection that is transmitted from other vertebrate animals to humans (Platto et al., 2020). There are approximately 1400 human pathogens, of which about 800 species are zoonotic (Levin, 2012). Globally, between 60 and 76% of emergent infectious diseases (EID)[1] are zoonoses (Jones et al., 2013; Rohr et al., 2019). Of the approximate 180 emerging or re-emerging pathogens in the past three decades, 130 are known to be zoonotic, with a dis-proportionate number of the new zoonoses being caused by RNA viruses (Levin, 2012). As with other EID, COVID-19 is provoked by the transmission of a pathogen from a vector natural species to others intermediate hosts, and to humans, also known as cross-species zoonotic spillover (Plowright et al., 2017). It represents a global public health burden which, while associated with multiple outbreaks, still remains a poorly understood phenomenon (Plowright et al., 2017). Our ability to identify these viruses is limited by gaps in disease surveillance and an incomplete understanding of the process of viral adaptation (Walker et al., 2018). Animal viruses must pass through a series of highly selective evolutionary bottlenecks to become established in the human population (Plowright et al., 2017). In the specific case of zoonosis, much attention is given to outbreak dynamics, vector control, and vaccine development, which is most understandably an anthropocentric viewpoint (Zeppelini et al., 2016). Although still preliminary, current data suggest that bats are the most probable initial source of the COVID-19 (Ashour et al., 2020), that begun on December 2019 in Wuhan, China. However, early presence also in Europe, before Wuhan's outbreak was notified, has been reported (Platto et al., 2020). But what are the causes for the emergence of a zoonosis? How an EID may transform in a pandemic, as in the case of COVID-19? And what role food systems play within all these pandemics' dynamics?

The pathways for the emergence of zoonosis include complex ecological and physiological, microbiological and epidemiological, but also behavioural processes that determine how the pathogens are distributed, released and disseminated, which is the likelihood, dose and route of exposure for humans and what's the susceptibility, and, therefore, the probability and severity of infection for a given pathogen dose (Daszak et al., 2013; Plowright et al., 2017). Several factors seem to contribute to the emergence of zoonoses and EID, including urbanization, population growth, wildlife trade, the loss of biodiversity and pathogen pollution through invasive species (Jones et al., 2008). Globally, almost half of these diseases seem to result from changes of land use and productive models (Keesing et al., 2010), which suggests a direct linkage between EID and industrial-scale globalized agricultural practices (Cárdenas-González and Álvarez-Buylla, 2020; Jones et al., 2013) that we refer here as agri-food systems. Arguably, in order to develop predictive models or build alert systems, the focus on zoonoses as ecological entities should be strengthen, given the huge diversity of aetiological agents, hosts, interactions, and abiotic dynamics (Zeppelini et al., 2016).

Discussions around food systems during this COVID-19 crisis have been prominent, coming from many different scientific disciplines and actors (Benton, 2020; HLPE, 2020; FAO, 2020a; IPES-Food, 2020; Ridolfi, 2020). First of all, because the emergence of the disease in China was initially attributed to a wet market, and this resulted in discussions around the need to close or not this type of markets (Petrikova et al., 2020; Walzer and Kang, 2020). From an ecological point of view, discussions around the role that industrial agriculture plays in the emergence of zoonosis is also gaining prominence (Altieri and Nicholls, 2020; Cárdenas-González and Álvarez-Buylla, 2020; Everard et al., 2020). From a social sciences perspective, discussions about the impacts have emerged in the form of comments and perspectives in specialised journals – such as Agriculture and Human Values, 2020 (Agriculture, Food & Covid-19), Food Ethics, 2020 (Ethical dimensions of COVID-19 and the

[1] The WHO defines 'emerging infections' as 'infectious diseases that have been identified and taxonomically classified recently. Some appear to be 'new' diseases of humans, others may have existed for many centuries and have been recognised only recently because ecological or other environmental changes have increased the risk of human infection.

food system), Food Security, 2020 (Worldwide disruptions of food systems and the search of enduring food security amidst Covid-19), Socio-Economic Planning Sciences, 2020 (Food loss and waste management during COVID-19) or Sustainability, 2020 (Human, Cultural, Social, Political and Environmental Dimensions for a New Vision of the Sustainable Agro-Food System Post COVID-19) – while the scientific community gathers more rigorous information about them. Yet, all this information is scattered and makes difficult to understand the central role food systems play in the COVID-19 crisis. In this article we aim at compiling and summarising, from a systems perspective, how food systems and COVID-19 are related.

Food systems are at the interface of human-nature relations and have been described as complex socio-ecological systems (Ericksen, 2008; Rivera-Ferre et al., 2013; SAPEA, 2020). A systems approach to the pandemics is essential to understand the different interactions among the social and ecological components of food. As such, food systems constitute an essential piece in the sum of probabilities that lead to the emergence of zoonoses, and food security is at risks due to the impacts of COVID-19 on all activities of the food system. In fact, there are relevant linkages between environmental, social and economic factors of food systems, and the emergence and spread of zoonoses, not only along the food chain, but also across scales, from local to global.

In this regard, characterising the relationship between COVID-19 and food is a difficult endeavour given the high diversity of food systems existing worldwide, each of which with different relations with COVID-type diseases. In the next section we elaborate on how global industrialised agri-food systems create the conditions that facilitate, directly or indirectly, the emergence of the disease [e.g. through deforestation and habitat fragmentation (Settele et al., 2020) or through industrial animal farming (Espinosa et al., 2020)]. However, it s in local food systems where the disease is first detected (e.g. wet market in Wuhan, China). Also, the policy measures adopted have different impacts on different food systems. Global and industrialised food systems have been heavily impacted through the limitations of labour force mobility or through workers being affected by the disease, while more local and small-scale farming systems have been highly impacted because of the prohibition of open markets where they frequently sell their food. The closure of institutional procurement and HORECA channels impacted all types of food systems. In all these cases, but not only, food security is at risk. We therefore explore global trends of food systems in relation to the COVID-19 pandemic and its impacts on both producers and consumers, following both a systems approach and a food security perspective, leaving the regional and more local impacts and responses to other articles in this special issue.

2. The contribution of industrialised agri-food systems to the global emergence of zoonosis

The emergence of zoonoses is a rare event in nature. However, multiple factors may disrupt the mechanisms that prevent the transmissions of pathogens from natural and intermediate hosts to humans, resulting in a zoonosis. Since 1940, agricultural drivers were associated with more than 25% of all, and > 50% of zoonotic EID in humans, and these proportions will likely increase as agriculture expands and intensifies (Rohr et al., 2019). Intensive and globalized agricultural and livestock systems (agri-food systems) are directly and indirectly contributing to the emergence and dissemination of zoonoses by weakening (Plowright et al., 2017):

1) the ecological barriers that govern the pathogens' pressure;
2) the mechanisms that regulate pathogens' release and dissemination;
3) the barriers that protect humans from exposure; and
4) the physiological barriers that decrease humans' susceptibility, once exposed to a virus.

Each of these phases of the zoonotic spill-over, from the reservoir to the host, is separated by a "barrier" and the spill-over requires the pathogen to cross every barrier through "holes" that need to be aligned in time and space (Plowright et al., 2017).

Significant changes have occurred in food systems in the last decades that have contributed to widen such "holes" in the barriers from phase to phase: agricultural intensification and industrialization (Matson et al., 1997) causing major environmental deterioration, the increasing distance travelled by food in global markets (Nayak and Waterson, 2019), and the nutrition transition towards diets rich in ultra-processed food and animal protein (Popkin et al., 2012) are the three cornerstones of such changes. Through high animal densities, mechanical innovations, the use of specialised animal feeds and additives and global trade, large-scale high-intensity animal farming has reduced meat prices globally at the expense of profound ecosystem and environmental changes. It is pointed out that crossing those barriers is linked to industrialized agricultural practices that, e.g., simplify ecosystem functions and connections, accelerate loss of biodiversity, favour the migration of wild species, accelerate generational succession rates that favour the selection of new strains of microorganisms, and increase worldwide movement of livestock production (live animals) that guarantees redistribution of these viruses into the continuum of anthropized ecosystems, despite health controls (Cárdenas-González and Álvarez-Buylla, 2020). Espinosa et al. (2020) reviewed recently the case of industrialized livestock farming (i.e. Intensive animal farming in which hundreds or thousands of animals, often of a single breed, are farmed in high-density closed facilities receiving large doses of antimicrobials and eating specific feeding compound), reporting several negative consequences leading to EID:

1) the increased scale of disease impact,
2) the immunosuppression of intensively farmed animals,
3) the risks of contamination for animals and humans living outside of farms, and
4) the risks associated with transportation.

In the following sections we describe in detail how industrial-scale agri-food systems contribute to increases in pathogen pressure; pathogen release and dissemination and humans' exposure; and humans' susceptibility to diseases.

2.1. Pathogen pressure

Pathogen pressure refers to the amount of a pathogen that is available to humans at a given point in time and space (Plowright et al., 2017). The series of processes that culminate in higher pathogen pressure include pathogen dynamics in reservoir hosts and the diversity of wildlife microbes in a region, the effects of environmental changes in wild populations' dynamics, the pathogen release from reservoir hosts, and the pathogen survival or dispersal outside of reservoir hosts. All these processes are severely affected by environmental changes. Probably land degradation, deforestation, habitat fragmentation and overall land-use changes are the most direct changes that affect the density and the prevalence of viruses and other pathogens, by influencing changes in ecosystems functionality, structure and dynamics (Lafferty and Mordecai, 2016; Sehgal, 2010; Wolfe et al., 2005).

Direct effects of logging and forest clearing for industrial agriculture are the alteration of habitats, fragmentation, increased abundance of ecotones and biodiversity loss. Particularly biodiversity loss might worsen the overall burden of infectious disease in human populations through several mechanisms (Table 1 below, Keesing et al., 2010; Myers et al., 2013). For instance, biodiversity loss can increase transmission if it reduces predation and competition on reservoir hosts, thereby increasing their density. This is the example of malaria (Pongsiri et al., 2009). However, pathogen transmission is not always a function of host density. Several studies have reported the "dilution effect", a mechanisms of reduction of human exposure to vector-borne diseases by

Table 1
Examples of driving factors that contributed to EID and spill over mechanisms which imply a connection to industrial-scale globalized agri-food systems.

Pathogen/disease/ species	Vector/Host species	Country	Year of EID emergence	Factors/drivers and spill over mechanisms	Reference
Nipah virus (paramyxovirus)	*Pteropus spp.* fruit bats	Malaysia	late 1990s	First, increased commercial pig production and patterns of dual use agriculture, created a pathway for the repeated transmission of NiV from fruit bat reservoirs to pigs. Second, the initial spillover primed the pig population for persistence of the pathogen on reintroduction, in turn, leading to increased transmission among pigs and to humans.	Daszak et al. (2013)
West Nile Virus (WNV) encephalitis	Mosquito-borne (*Culex sp.*) disease. Wild birds (passerine as preferred vector and non-passerine as alternative vector) serve as the primary reservoir hosts	North America	1999	Virus amplification rates were lower at sites with more non- passerine species. Land cover changes related to intensified agri-food systems alter diversity of non-passerine species.	Ezenwa et al. (2006)
Hemorrhagic fever with renal syndrome (HFRS) viruses (hantaviruses and adenoviruses)	Rodents (Muridae)	Asia, Europe (North America)	I World War (described 1993)	Land conversion to pasture and agriculture. Many specialist species become locally extinct, and the assemblage becomes species depauperate, often restricted to a few opportunistic species whose population densities may increase dramatically under release from competitive pressures.	Mills (2006)
Lyme disease	The deer tick (*Ixodes scapularis*) is the vector and white-footed mouse (*Peromyscus leucopus*) and deer (Cervidae) are among the hosts.	Central Africa	-	Forest fragmentation increases the relative abundance of the highly competent reservoir, the white-footed mouse, what results in a higher risk for infection to humans	LoGiudice et al. (2003)

increasing diversity of vectors species (Holt et al., 2003; Keesing et al., 2010; LoGiudice et al., 2003; Schmidt and Ostfeld, 2001; Telfer et al., 2005). The dilution effect predicts that infection rates among vectors, and ultimately human infection risk, will be lower in highly diverse host communities where incompetent reservoir hosts dilute rates of disease transmission between vectors and highly competent hosts. In several case studies, the species most likely to be lost from ecological communities as diversity declines are those most likely to reduce pathogen transmission, while the host resilience increases. This is the case of West Nile encephalitis (Table 1 below, Pongsiri et al., 2009). In some other cases, the loss of vertebrate reservoir host species richness due to deforestation and forest fragmentation has resulted in increased abundance of highly competent reservoirs of some zoonotic agents, increasing the risk for transmission to humans (LoGiudice et al., 2003). In addition, feedbacks between poverty, habitat transformation, biodiversity loss, soil degradation and infectious diseases have been described (Rohr et al., 2019).

In the last decades, the industrialization, intensification and globalization of agri-food systems have been responsible for important disturbances to ecosystems' functions and connectivity which have altered the migration patterns of wild species and fostered the accelerating generational succession rates. In fact, another direct factor of spill-over is the change in the distribution of host species (i.e. reservoir and vector species) due to both landscape alterations and/or climate change, such as the change in species distribution, migration patterns and changes in the ecology of pathogens. The movement and behaviour of hosts affect contact and the likelihood of exposure within and between species. For example, loss of suitable habitats could alter bird diversity or migration patterns, with results similar to what is expected with climate change (Gilbert et al., 2008). Such altered flyways or increasing bird trafficking can result in species redistributions, again leading to increased interspecies contacts and transmission of pathogens between birds and to humans (Sehgal, 2010; Wolfe et al., 2005). This is for instance the case of the West Nile encephalitis (Table 1).

Other characteristics of the industrialised and globalised agri-food system affecting pathogen exposure are the increased densities in humans and livestock, which increase contact rates and thus transmission, the increase in human-wildlife interactions associated to the conversion of natural ecosystems to croplands or rangelands (Rohr et al., 2019), and the worldwide movement of animal products (e.g. live animals) that contributes to the spread of these viruses (Cárdenas-González and Álvarez-Buylla, 2020).

2.2. Pathogen release and dissemination and humans' exposure

Once the pathogen abandons the natural environment and is scaled out by the natural host, it may jump from host to host and to humans, i.e. zoonosis spillover. Release and dissemination of pathogens is also favoured by environmental changes, such as climate change, as well as to other activities linked to current industrialised agri-food models that cause e.g. soil degradation, deforestation, intentional burning, excessive ploughing and inundation by irrigation or indiscriminate use of agrochemicals (Lal, 2020). Such environmental changes cause habitat changes, species displacement, disturbance of host-parasite dynamics, including the type and the occurrence of contacts between humans and other animal species (Daszak et al., 2013). For instance, spring and summer outbreaks of haemorrhagic fever with renal syndrome have been reported in agricultural settings in Asia and Europe associated to human contact with field rodents through the planting and harvesting of crops (Schmaljohn and Hjelle, 1997).

Soil erosion and degradation associated with land-use change has been related to the frequency of dust storms and the release of volatile compounds and biota in air (Garrison et al., 2003). The IPCC (2019) found that when cultivated without conservation practices, soil is currently eroding up to 100 times quicker than it is forming. Airborne particles in the dust might transport spores, organisms and pathogens: about 20 human infectious disease organisms, like anthrax and tuberculosis, are easily carried in the soil particles transported by the wind (Griffin et al., 2001). Dust also irritates the eyes and respiratory passages, aggravating symptoms of infectious diseases (Pimentel et al., 1998). In fact, global loss of topsoil because of unsustainable agricultural practices aggravated infectious diseases like Ebola and Marbug virus (IPBES, 2018); and the highly increased frequency of dust storms in the United States has shown high correlation with Valley fever incidences (Tong et al., 2017).

It is also likely that climate change will contribute to novel occurrences of disease emergence and transmission (Jones et al., 2008; Lafferty and Mordecai, 2016; Patz et al., 2008; Rogers and Randolph, 2006; WHO and CBD, 2015; Table 1). For instance, changes in temperature and precipitations directly affect the spread of virus. Recent studies demonstrated that the increasing mean of temperatures was positively correlated with the incidence of Crimean-Congo Haemorrhagic Fever

(Vescio et al., 2012). Similarly, Tesla et al. (2018) demonstrated that Zika disease in tropical and template regions is mainly driven by increasing temperatures that affect transmission efficiency and mosquito survival. They further link land use change that modifies the microclimates mosquitoes experience and human density and exposure with the transmission of Zika virus, which might explain the explosive spread of Zika virus in urban centres throughout the Americas. Thawing of permafrost is exposing cattle burial grounds, what increases the risk of people coming into contact with infected carcasses, hawed spores, or unknown viruses that were previously trapped in soils or ice, what could also potentially influence EID (Waits et al., 2018). This has been the case of anthrax spores in the Arctic (Revich et al., 2012).

Intensive livestock production amplifies the risk of dissemination due to the confinement of high number of animals with a narrowed genetic diversity in small spaces (Espinosa et al., 2020). Normally, when a new pathogen emerges in a host population, and assuming it is transmitted directly from host to host, it gradually moderates its virulence in order to keep those hosts alive for long enough to spread it far and wide (Rohr et al., 2019). But in industrial farms – where animals are densely packed together and host-to-host transmission is easy – the evolutionary pressure on the pathogen to moderate its virulence is relieved (Lenski and May, 1994). And because those animals tend to be genetically close to each other, a pathogen introduced into that population can race through it without any genetic “firebreak” to slow its progress. Gilbert et al. (2008) discussed how the emergence of avian influenza in China was linked to rapid intensification of the poultry sector. Trade networks and live-poultry markets further exacerbated the spread and persistence of avian influenza as well as human exposure.

After dispersion in intermediate host, human and animal behaviour determine pathogen exposure, specifically, the likelihood, route and dose of exposure. Another mechanism to amplify the risk of dissemination of pathogens from a vector host to another, and the exposure of humans, is the interaction of animals and humans with wildlife. Indeed, occupational interactions with reservoir host animals, the consumption of certain animal products or the use of particular environments, may increase the risk of infection by pathogens (Macpherson, 2005). Several studies have demonstrated that the emergence of zoonosis from hunting and eating wildlife is still of global importance because of increases in human population density, globalized trade, and consequent increased contact between humans and animals. More than 70% of the zoonotic EID events were caused by pathogens with a wildlife origin—for example, the emergence of Nipah virus in Perak, Malaysia and SARS in Guangdong Province, China (Jones et al., 2008). One study related bushmeat consumption in Cameroon and EID, including HIV/AIDS, Ebola and Marburg viruses (LoGiudice et al., 2003). The authors also evidenced that bushmeat plays an important dietary role among poor households.

Agricultural irrigation is yet another mechanism that can exacerbate infectious diseases. Irrigated lands accounted for much of the increased yields experienced during the Green Revolution (Rohr et al., 2019), and the expectation is that they will keep expanding at least while climate change allows. Although wetlands often decline with agriculture, therefore reducing the habitat for certain vectors such as mosquitos for malaria, dams, reservoirs and irrigation networks often increase. As Rohr et al. (2019) review, this redistribution has been associated with increases in other vectors and intermediate hosts of human pathogens, such as the mosquito hosting the elephantiasis in Egypt, or the increase of malaria after the construction of irrigation systems in Sri Lanka, India or Ethiopia.

Another mechanism that facilitates the global spread of new zoonoses and the humans’ exposure is the elongation of food supply chains, largely across international borders (23% of the food products is traded globally) (D’Odorico et al., 2014), and the increased frequency, speed and volume of human travel and migrations (Rohr et al., 2019). The globalized nature of industrialised agri-food systems and increases of air and sea travel and intermediaries globally, may explain how some diseases became rapidly pandemics (McNeely, 2021). For instance, vessels were among the first identified sources of global contagion of COVID-19: Here, tight working and living quarters present risk for workers, and vessels can spread disease to multiple locations as they move across oceans (Havice et al., 2020).

Finally, the intensification and expansion of agriculture and livestock systems entails increases in the use of biochemical agricultural inputs (e.g. pesticides, antibiotics, growth promoters), which are known to have direct effects on EID affecting humans. It also contributes to the emergence of wildlife diseases that constitute important sources of EID in humans (Rohr et al., 2019). For instance, insecticide resistance is expected to increase due to the intensification and simplification of agriculture, potentially posing relevant challenges for the control of diseases carried by insect vectors (Rohr et al., 2019). In addition to the increase in antibiotics and pesticides, the application of nitrogen and phosphorus-based fertilizers has boosted with the intensification of agriculture. The effects of nutrient enrichment on disease are indirect and complex, with some infections increasing and others decreasing, but a recent review on the subject suggest that elevated nutrient levels might exacerbate the impact of infectious disease (Johnson et al., 2010).

2.3. *Humans’ susceptibility to diseases*

Agricultural development can yield direct improvements to nutrition, and through several mechanisms, nutrition can be a critical determinant of infectious disease susceptibility and progression (Civitello et al., 2018). However, the current globalised and industrialised agri-food system is far from ensuring global food security, including adequate nutrition to large shares of the population (Oteros-Rozas et al., 2019).

Genetic, physiological and immunological attributes of the human host, together with the dose and route of exposure, affect the probability and severity of infection, i.e., the susceptibility of humans to the disease (Plowright et al., 2017). Among the several factors that may influence in a non-linear way the interactions between dose, timing of exposure and probability of infection, we highlight the immunological and physiological state of the host. Malnutrition and undernutrition, overweight/obesity, and/or micronutrient deficiencies as well as weaknesses of immunity systems may be cause of major susceptibility of humans to pathogens such as COVID-19 (Fedele et al., 2021). Thus, the dietary shifts associated to industrialised food systems in the form of nutrition transition (Gillespie and van den Bold, 2017), and malnutrition in general, may contribute to increase human exposure to EID. Malnutrition severely weakens people’s immune systems, increasing people’s chances of getting ill, staying ill, and dying because of illness, suggesting the relevance of nutritional, safe and quality food in increasing susceptibility to EID (Pate and van Nieuwkoop, 2020). Some diseases, in addition, place direct demand on host nutrition, cause eating disorders or tissue damage that is costly for the host, therefore further worsening its nutritional status and therefore resistance and tolerance to infections (Rohr et al., 2019). Emerging evidence suggests that people with pre-existing, diet-related conditions such as severe obesity, heart disease, and diabetes, are suffering more serious consequences from COVID-19, including more severe illness and a greater need for intensive health care (Zhou et al., 2020).

Finally, despite not being related to COVID-19, antimicrobial resistance developed due to the widespread use of antibiotic drugs in industrialized livestock farming and aquaculture (Van Boeckel et al., 2015) contributes to failure of treatments and therefore increased humans’ vulnerability to EID (Rohr et al., 2019). Alarming levels of antimicrobial resistance have been reported in countries of all income levels (Van Boeckel et al., 2015, 2019). Possible causes of the development and spread of such resistance are the misuse and overuse of antimicrobials to promote growth and routinely prevent disease in animals, especially in intensified livestock farms, and crops, without appropriate indication and in the absence of good agricultural practices (Van

Boeckel et al., 2019).

3. The impacts of COVID-19 on food systems and food security

Food system refers to all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food and the outputs of these activities, including socio-economic and environmental outcomes (HLPE, 2014). The impacts of COVID-19 on food systems can be divided between direct impacts of the disease on the system, and indirect impacts derived from the policies adopted in the context of the pandemic, at different levels (from local to global). They can also be classified according to the duration of the impact, having short-term and long-term impacts. It is also important to highlight that impacts have been different for different types of food systems, as also the capacity to respond to those impacts varied across countries and regions. As previously stated, in this article, we focus on global trends and it is out of our scope to analyse the impacts and responses of the different types of food systems. However, we believe it is equally important to avoid universalization of impacts and responses.

3.1. Impacts of COVID-19 on food supply chains

COVID-19 has had impacts on all the components and activities of the food system, affecting the functioning and operation of the system through all over the food supply chain, from production to consumption, including food loss and waste.

3.1.1. Food production

At the production side, travel restrictions in most countries worldwide have affected the delivery of agricultural inputs such as fertilisers, seeds or pesticides for many farmers, therefore increasing their prices. This is the case derived for instance from the Chinese lock-down, a major producer of synthetic agricultural inputs (Petetin, 2020). Also, the mobility barriers imposed have reduced the labour force available to harvest and collect, resulting in a lack of seasonal workers (Kolodinsky et al., 2020; Larue, 2020; Petetin, 2020) and huge impacts on globalized food systems that are heavily dependent on migrant seasonal workforce (Nestle, 2020). This situation evidenced the contradictions of globalized industrial food systems, for instance frequently considering migrant farmworkers as “illegal”, yet “essential” during the pandemic (Graddy-Lovelace, 2020).

In the production side, there have also been difficulties to place the product in the market due to, among others, the lock-downs which have prevented rural farmers to sell their products in urban markets, the reduction of public procurement (due to e.g. closure of schools), or the closure of HORECA (Hotel, Restaurant, Catering) channels. The closure of HORECA has been particularly dramatic in livestock systems (e.g. milk and meat), in which farmers have been forced to throw out their products (Petetin, 2020) and slaughter their animals (OECD, 2020) as a result of the collapse of the demand. Thus, many of the problems on the production side are food losses due to the lack of labour force and/or the closure of HORECA channels (Barling, 2020). In Australia and New Zealand, the market closure was particularly noted in rigid, steady throughput perishable industries (e.g. chicken and pork) (Snow et al., 2021). From a risk perspective, the pandemic has shown the high level of farmer’s exposure due to their dependence on other actors in the food chain to gather inputs and to sell their products. Fisheries were also heavily impacted. Mobility restrictions were applied and many ports either banned shore leaves and crew changes, or required 14-day quarantine (Havice et al., 2020).

3.1.2. Food processing

The processing industry has been highly affected by the pandemic. This can be exemplified through the particular case of the meat, with abattoirs/ slaughterhouses and meat processing plants being hotspots of the virus transmission in different countries, such as Germany (slaughterhouses of Tönnies group in North Rhine-Westphalia), USA and Canada (Weersink et al., 2020), with several thousands of workers affected worldwide (Middleton et al., 2020). Not only the temperature and humidity conditions and metallic surfaces inside the manufacturing buildings are particularly favourable for the permanence of the virus, but also poor labour conditions: workplaces are crowded, social distancing is difficult and workers must speak loudly over the noise (Middleton et al., 2020). As a result, there is a reduced activity in the industry forced by the lack of labour, with many workers being infected by the virus. The closure of the food processing industry also impacts back to the production, since farmers cannot deliver their products for processing. Indeed, euthanizing animals to prevent overcrowding has been one of the effects of processing disruptions (OECD, 2020).

3.1.3. Food trade and distribution

In the distribution sector, the main impacts have been associated to the mobility restrictions imposed to avoid the spreading of the virus, including export restrictions by some countries (Petetin, 2020). Long supply chains have been particularly affected by the pandemics, with logistics interruptions and limited access to markets creating significant disruptions along the food supply chain (HLPE, 2020; Mussell et al., 2020). Failures in logistics and distribution chains have been reported with different impacts in different regions, by sector and depending on the transport type (Hobbs, 2020). For instance, rail and truck transport was not significantly reduced in North America, as compared to bulk ocean (Gray, 2020). Interruptions and disruptions in food chains often resulted in unsold agricultural products and in significant increases in food loss and waste, especially of perishable products (e.g. fruits and vegetables, fish, meat and dairy products) (FAO, 2020b).

3.1.4. Food retailing

COVID-19 has affected where and how consumers buy their food (Cranfield, 2020). With the shutdown of restaurants, cafes and other food services, food purchases switched to grocery stores (Goddard, 2020). The retailing sector has dealt with major pressure as demand rose and there was a need to guarantee sufficient stocks. Yet, from an economic perspective, the retailing industry has been positively impacted by the COVID-19 with a notable increase of demand and in many cases providing new jobs to meet the high pressure of restocking shelves (Nicola et al., 2020; Petetin, 2020). The retailing sector has been one of the so-called “essential” economic sectors and its activity has not ceased during the lock-down in any country, contrary to the closure of other open-air spaces, such as farmers’ markets. In many countries (e.g. Spain), farmers’ markets were closed limiting the available options to consumers, who could then access food almost only through major supermarkets. Thus, small-scale farmers, who used to sell their products in open-markets, could not do so while the retailing industry increased its sales because all other channels were temporarily closed. Still, there were shortages in some products due to interruption of the delivery, lack of capacity to adapt to the new situation in the supply chain or a sharp increase in demand, e.g. flour or baby formula.

It is remarkable that one option that has grown exponentially during the pandemics has been e commerce and on-line delivery (Hobbs, 2020; Information Resources Inc., 2020). Since physically shopping in a grocery store was perceived as a risk, consumer buying patterns shifted to online shopping (Baker et al., 2020; Brick Meets Click, 2020; Grashuis et al., 2020). The high demand during the lock-down affected online food delivery e.g. companies have struggled with excessive bookings, with deliveries arriving late or, sometimes, not at all, as in the UK (BBC News, 2020).

3.1.5. Food consumption

Food habits and consumption patterns have been reported to change rapidly and unprecedentedly during the pandemics (OECD, 2020). At the beginning of the epidemic, panic buying of non-perishable food

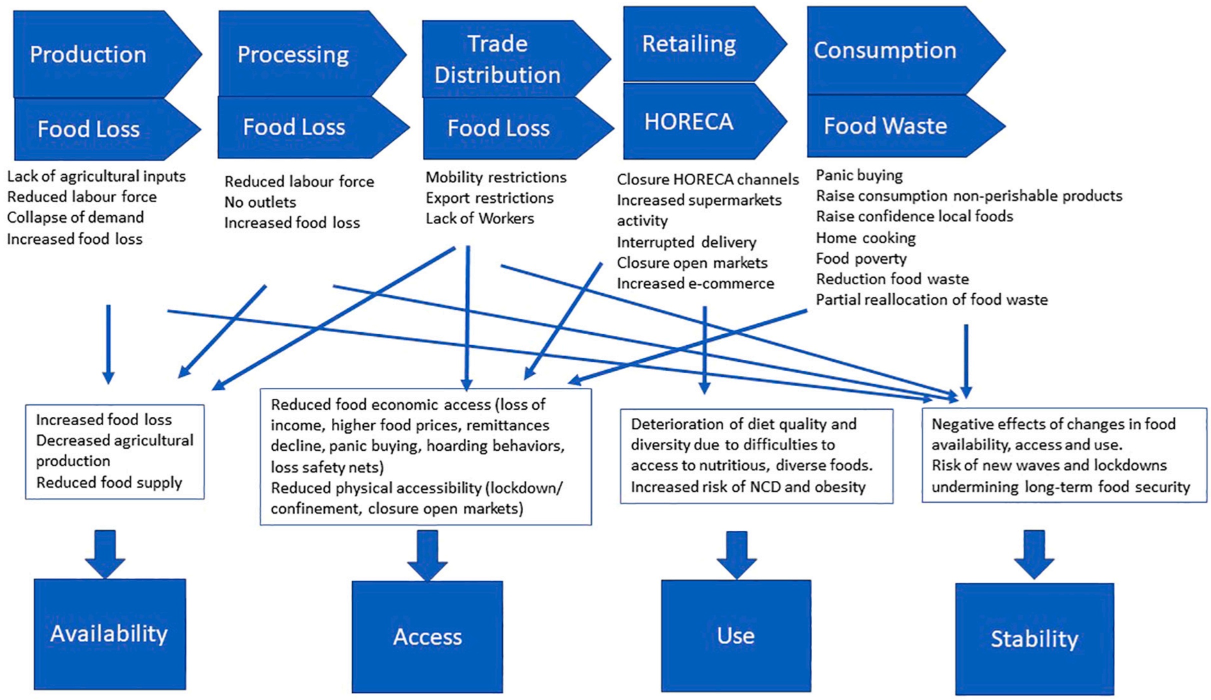

Fig. 1. Impacts of COVID-19 on agri-food supply chains and food security

items (e.g. pasta, rice, canned goods, flour, frozen foods) was observed throughout the world (Baker et al., 2020; Cranfield, 2020; Grasso, 2020; Richards and Rickard, 2020; Zheng et al., 2020). An increase in consumer confidence in local food, including organic production (Petetin, 2020) and local food movements, has been observed (Correra et al., 2020; Darnhofer, 2020; Hobbs, 2020). Due to the lock-down and closure of HORECA channels, people have increased home cooking. After some panic buying at the beginning of the pandemics, which determined some shortages and increased prices of some products, later on the behaviour of consumers stabilized. Still, a bulk of impacts on food consumption is expected to derive from the socio-economic crisis resulted from the pandemic, with an increase in the number of people with reduced purchasing power. Indeed, food poverty episodes are expected to increase in the future (HLPE, 2020; FAO, 2020a).

3.1.6. Food waste

Data on food waste is quite heterogeneous. Jribi et al. (2020) underlined that COVID-19 lock-down pushed toward a positive behavioural change regarding food wastage in Tunisia. However, in Spain, Aldaco et al. (2020) revealed that there was no significant adjustment in overall food waste generation during the first weeks of the COVID-19 lock-down, but a partial reallocation from extra-domestic consumption to household consumption (with a 12% increase in household food waste). Indeed, another potential change due to COVID-19 is the rise of home-prepared meals (The Food Industry Association, 2020). In Italy, Di Renzo et al. (2020) showed an increase in the use of leftovers during the COVID-19 lock-down with a consequent reduction in food wastage.

In sum, all the different components of the food supply chain have been affected directly or indirectly by COVID-19 (Fig. 1). Thus, the significance of COVID-19 for food supply chains comes not only from its impact on primary production or overall food demand, but mostly from its disruptive effects on the complex web of actors connecting farm to fork, and the sudden change in the demand mix (OECD, 2020). All these impacts are affecting the food security of millions of people, currently and will most likely do it in the short and mid-term future, especially in developing countries, where social safety nets are less well-developed (OECD, 2020). In the following section we describe how the four dimensions of food security were and will be affected by the COVID-19 pandemics (Fig. 1).

3.2. Impacts of COVID-19 on food security

All four dimensions of food security (availability, access, use and stability) have been seriously affected by the COVID-19 pandemic (HLPE, 2020; Devereux et al., 2020), due for instance to impacts on the food chain, with a greater effect on the most vulnerable population groups (Power et al., 2020; United Nations, 2020b). Moreover, the FAO estimates that the food security and nutritional status of the most vulnerable population groups is likely to deteriorate further, due to the health and socio-economic impacts of the COVID-19 pandemic. In the last SOFI report, FAO et al. (2020) calculated that the COVID-19 pandemic would added between 83 and 132 million people to the total number of undernourished in the world in 2021 depending on the economic growth scenario (losses ranging from 4.9 to 10 percentage points in global GDP growth), mostly through impacts on food availability and food access.

But COVID 19 pandemic represents a challenge for food security not only in developing countries (CIHEAM, 2020; FSIN, 2020; The United Nations System Standing Committee on Nutrition, 2020), but also in developed ones (Deaton and Deaton, 2020). COVID-19 affects both the supply side and the demand side of the food chain. However, Schmidhuber et al. (2020) argue that "*While food and agricultural systems are exposed to both demand and supply side shocks (symmetric), these shocks are not expected to take place in parallel (asynchronous) since, inter alia, consumers can draw on savings, food stocks and safety nets*".

3.2.1. Food availability

Food availability is determined by the physical amount of food. It is most often affected when there is a reduction in the production of food, but also when there are interruptions in the processing, distribution and exchange of food. Direct impacts on food availability arise from the infection of workers that reduce the labour availability all along the food system, from the farm to the processing industry and retailing; as well as disruptions to the transportation networks, as described in the previous section. Indirect impacts arise from the movement restrictions, imposed quarantines and self-isolation, particularly relevant for trade of perishable and seasonal products. A particular case linked to the structure of the market was the major short-run disruptions that COVID-19 pandemic had on meat processing and marketing (Thilmany et al., 2020) due to high market concentration in a few firms. In many countries, farmers have been burying perishable produce and dumping milk as a result of falling consumer demand and/or supply chain disruption (United Nations, 2020b). Here, we can observe that the effects of COVID-19 pandemic on food security differs not only among socio-economic groups (with higher impacts on vulnerable ones) but also among age groups. As for children and teens, school closures reduced the number of meals available to them (Rundle et al., 2020).

3.2.2. *Food access*

Main impacts arose from the closure of food markets, which limited the options available to consumers, who turned to rely mostly on major supermarkets. Changes in the prices of fresh products also had impact on food access. There is still a lack of information on whether food retailers, which increased their power within the food chain, being in many cases the almost only option for consumers to access food during the lockdown, took advantage of the pandemic by either raising prices to consumers or lowering prices paid to suppliers (Hart et al., 2020). In some places such as New Zealand, the inefficiency of the food system and the reduction in the number of places where to find food to only supermarkets, resulted in sharp increases of prices of vegetables s (NZ Herald, 2020; Stats NZ, 2020). In its recent report on the impacts of COVID-19 on food security in eastern and southern Mediterranean countries, CIHEAM (2020) reported an increase of prices of some agri-food products such as milk in Albania; meats, fruits and vegetables in Algeria; pasta and rice in Egypt; and fruits and vegetables in Tunisia. In Lebanon, the impacts of the financial crisis combined with those of COVID-19 led to an increase of the prices of all food products.

Another indirect impact deriving from the socio-economic impact of the pandemic are food poverty episodes, with thousands of people losing their jobs and sources of income and, as a consequence, their purchasing power to buy food. Indeed, the number of people needing assistance from food banks increased, and the budget allocated to food aid did so accordingly. For instance, the US Federal Reserve approved $25bn in food assistance (Nicola et al., 2020), the Catalan government provided 4 million € to buy fresh food from small farmers, whose selling channels were closed, to provide to the Food Bank Foundation (Generalitat de Catalunya, 2020) and the UK government provided vulnerable populations with food parcels and free meals to collect and take home. However, it is important to consider whether the increase of the number of people seeking assistance from food banks might also be a result of the failure of government policies to strengthen social safety nets.

3.2.3. *Food use*

Mattioli and Ballerini Puviani (2020) stated that, due to the perceived stress concerning food shortages, people preferred packaged and long-lasting foods instead of fresh food. During the pandemic, and particularly at the beginning, short-run panic behaviour among consumers led to increases in buying non-perishable products (Hobbs, 2020; Nicola et al., 2020). This could result in changes on diets with impacts on food security. In that manner, impacts on food use arose mainly from the increase in consumption of processed cheap and empty calories food. Beside changes in diets, weight gains might be a result of reduced opportunities for physical exercise, by adults as well as teens/children, caused by lockdowns and mobility restrictions measures. Increases in food intake (especially so-called 'comfort food' such as desserts, chocolate and ice cream) and weight gains among adults during the lockdown period have been reported in Italy (Di Renzo et al., 2020; Scarmozzino and Visioli, 2020). Ammar et al. (2020), in their international research on the effects of COVID-19 outbreak on lifestyles, highlighted that food consumption patterns were more unhealthy during the lockdown, and that the confinement measures altered physical activity and eating behaviours in a health-compromising direction. In particular, school closures may have aggravated childhood obesity and increased disparities in obesity risk since they also could well be exposed to more shelf-stable food, while their physical activity decreased (Rundle et al., 2020).

4. Main policies implemented in the face of the COVID-19 pandemic, and their effects on the agri-food domain

At a global scale, the confinement of people and strong limitations on the movement of products have been the key policy measures to reduce the spread of the COVID-19 pandemic. Such measures have created additional stress in food systems through impacts on different elements crucial for an appropriate functioning of the agri-food supply chain. The effects of these policy measures on the agri-food domain have been numerous (as mentioned above). As follows, we identify and group i) the main policy measures affecting agri-food systems as well as ii) those policy measures issued to minimize the impacts of the pandemic on food security and on the agri-food sector. We do not present here other type of measures, as those implemented by some local governments to support mutual aid processes (Moragues-Faus, 2020). Most of the sources used to identify the measures described do not come from academic references but from government, international organizations and specialised and mass media webpages. To expand the policy options available, the search was conducted in three languages (Spanish, English and French). The search was stopped when no more diversity of policies was identified. We present here only a selection to exemplify the diversity of policy measures.

Export and trade restrictions to guarantee national food security of some staple food were implemented by some countries, as it is the case of Kazakhstan, Russia or Vietnam (Carles and Courleux, 2020; Glauber et al., 2020). In past food crises, this entailed rising prices and increased world food insecurity (Hendrix, 2020). Export restrictions introduced by some wheat exporting countries (e.g. Romania, Ukraine, Kazakhstan) in April 2020 affected wheat imports by Egypt (CIHEAM, 2020).

Closure of local food and peasant markets while supermarkets remained open, with the consequences this entails, first in relation to the discrimination in favour of supermarkets to the detriment of small producers, and second in relation to a shift in consumption from fresh to processed food (Associazione Rurale Italiana, 2020; FIAN, 2020; Snow et al., 2021). In some countries, these measures run also in parallel with closure of informal markets and illegalization of street vendors, with the obvious effects in the marginalization of the vulnerable people that tend to be involved in these activities (FAO, 2020d).

Closure of schools, social assistance centres and food shelters, with the derived cancellation of the meals being offered in these places, which is the only adequate source of nutrition for particular groups of vulnerable people and households (FAO, 2020c, 2020d; FIAN, 2020).

Policy measures to support specific agriculture sectors in getting access to the market, improving their productivity, minimizing food loss and waste, managing surpluses, and developing e-commerce. These measures focused especially on smallholders (CONTAG, 2020; EC, 2020; FAO, 2020c, 2020d), those that were obliged to close, and those sectors largely linked to tourism or leisure time activities that were among the most affected (e.g. viticulture or brewery). Among the measures being reported we found: forgiveness of social contributions, partial unemployment benefits, transformation of surpluses into alcohol, private storage aid, aid for destruction of surplus agricultural produce, aid to storage products from livestock, measures to redirect the production towards animal feeding or mechanization, higher advanced payments, extended deadlines to submit payment requests, and paperless regularization (Agri-Mutuel, 2020; California Department of Food and Agriculture, 2020; EC, 2020; Verdú, 2020).

Measures to increase the flexibility of the seasonal labour market, such as allowing the movement of seasonal agricultural

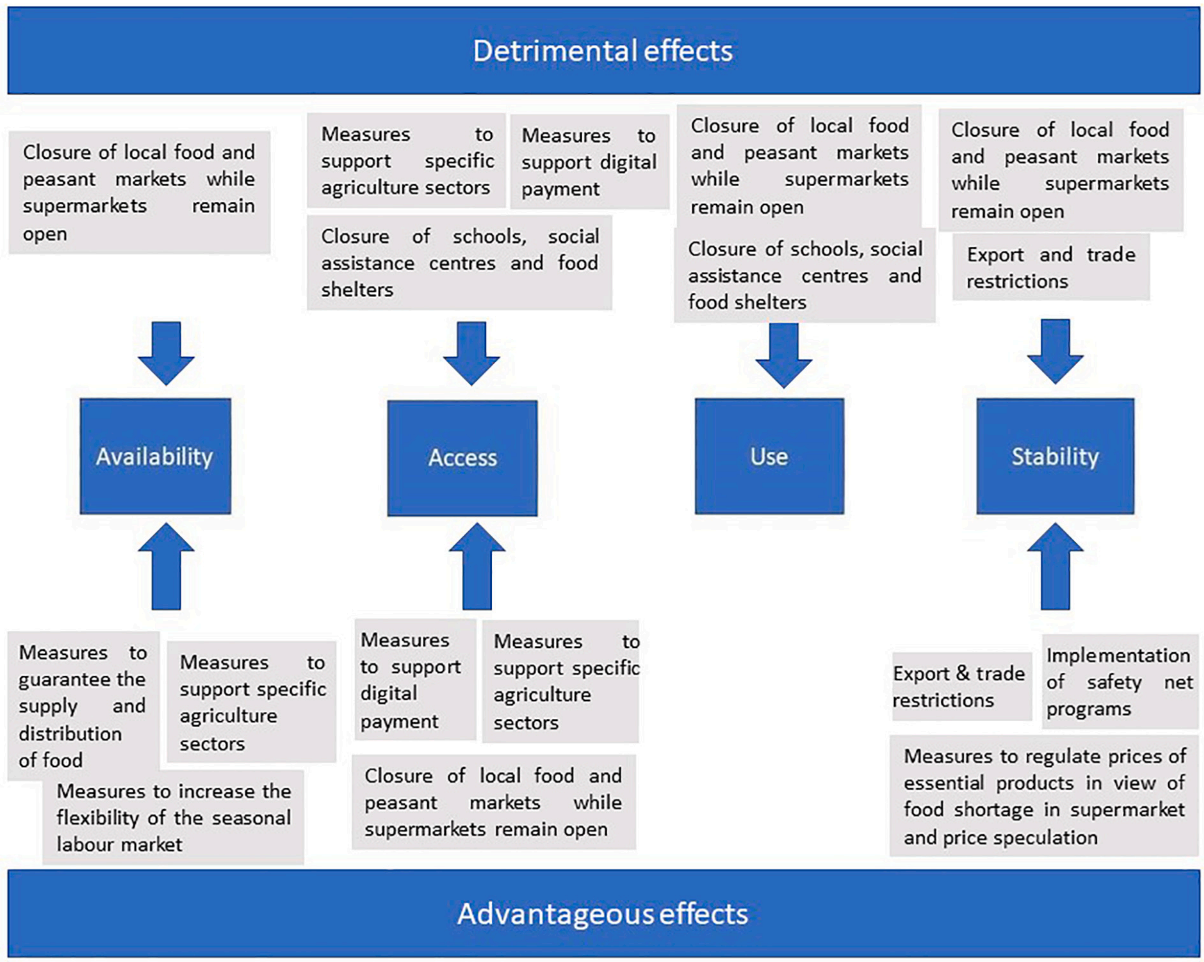

Fig. 2. Advantageous and detrimental effects on food security of the agri-food policies developed during the COVID-19 pandemic lockdown.

workers, or even exceptional measures allowing seasonal agricultural workers to combine working with unemployment benefits, as those being implemented in France (Ouest-France, 2020), Spain (issue of a Royal decree law on urgent measures on agriculture employment), Italy with an extension of residence permit (ANSA, 2020a, 2020b; Canali, 2020; Palumbo and Corrado, 2020), Germany with a temporal modification of the national employment legislation to allow the entrance of seasonal workers without work permit (FIAN, 2020; Info Migrants, 2020) or Portugal (Reuters, 2020).

Measures to guarantee the supply and distribution of food, such as facilitating the movement of food commodities in Italy or extra funds devoted to improve supply and the related logistics in China (FAO, 2020d; Government of China, 2020; Government of Italy, 2020; Han, 2020; Shang and Yang, 2020).

Measures to regulate prices of essential products in view of food shortage in supermarkets and price speculation. CIHEAM (2020) lists different examples of actions taken by Mediterranean governments (cf. Albania, Algeria, Egypt, Lebanon, Morocco, Tunisia) to contain food prices; these include initiatives to influence directly the food distribution channels as well as others relating to the management of the stocks of staple products (e.g. wheat, rice). FIAN (2020) reported how government in Argentina and Colombia introduced measures to regulate prices of essential products.

Measures to support digital payment, with the effects of marginalizing those peoples with no access to such kind of payment systems (FIAN, 2020).

Implementation of safety net programs, being applied universally to all citizens of a given region or country, or to particular groups of population (such as those unemployed, those taking care of others, those running small businesses, those under situations of damaged access to food, or elderly people), with measures such as public procurement (Borkowski et al., 2020; FAEP, 2020; FAO, 2020c, 2020d; FIAN, 2020; Government of the United Kingdom of Great Britain and Northern Ireland, 2020). Some Mediterranean governments took different actions to protect vulnerable groups of the population (CIHEAM, 2020); Algeria provided food baskets to 400,000 families and a direct financial transfer of 10,000 Dinars (roughly 70€) to 2.2 million poor households., whereas in Lebanon the food support component within the National Poverty Targeting Program (NPTP), which reaches monthly 43,000 households, was increased in April 2020 from LBP 40,500 to LBP 50,000 to compensate for the increase in food prices. Fig. 2. Impacts of the policies facing the COVID-19 outbreak on the four dimensions of food security

5. Vulnerability of food systems to the COVID-19 pandemic

To have a more accurate comprehension of the effects of the COVID-19 pandemic, we have applied the vulnerability framework (Adger, 2006) to re-examine the above-mentioned trends and transformations. This framework pictures the vulnerability of a given system as depending on its performance in three dimensions viz. exposure, sensitivity and adaptation, which in our case are defined as:

- exposure of the food systems to the impacts of the covid-19 demonstrated by the transformations caused by the covid-19 crisis

- sensitivity of the food systems to the exposure to the COVID-19 pandemic, demonstrated by the impacts of these transformations on the agri-food systems, and
- adaptation of the food systems demonstrated by the strategies set in place to minimize the damages or maximize the advantages that arise from the new emerging circumstances derived from the COVID-19 pandemic.

The three main trends and transformations to which food systems have been exposed due to the COVID-19 pandemic have been economic lockdown, people confinement, and coronavirus infections to people. Such exposure has resulted in the food systems being sensitive to direct and indirect impacts. Direct impacts are those derived from people being infected, and indirect impacts are those caused by the multiple policy measures being adopted. Among them:

- rising unemployment,
- prohibition of local open-air markets,
- closure of businesses,
- diminishing availability of labour (predominantly migrants, with particular impact on large food processing industries and with specific relevance to the meat sector),
- disruption of supply chains (particularly meat, tourist-related and perishable produce),
- large constraints in transportations of people and goods and inputs,
- collapse of markets,
- food waste and loss,
- large constraints for food movements and particularly exports,
- increase price of food, and
- food insecurity of those more vulnerable groups (among them children, as a consequence of the lack of access to school lunches).

When exposed to these impacts, agri-food systems have responded with a number of adaptation strategies, as shown in the sections above, namely:

- increase in purchase of non-perishable food items (and storage),
- activation of multifaceted social safety nets,
- developing of the e-commerce,
- shift in consumption from HORECA channels to grocery stores and home cooking,
- increase in local and organic food,
- increase in consumption of processed foods, and
- burying and/or dumping of perishable produce.

The existence of an enormous number of realities, considering the regional specificities, different types of food systems, different situations in the stages that conform the food supply chain, and the time horizon of the impacts (short- or long-term) which are still ongoing, draws a complex picture. However, despite this complexity, the trends that emerge from this examination point at global food systems as highly vulnerable to pandemics. Indeed, larger difficulties in accessing agricultural inputs and migrant workers, increasing difficulties in running exports, and the large amount of direct impacts being suffered by the food processing industry, point out that globalized food systems showed a larger degree of vulnerability to the COVID-19 pandemic than less globalized ones. Yet, short circuits and small farms also have some disadvantages in this context. Small firms are often more labour intensive than large firms and thus are more vulnerable to disruptions (Hobbs, 2020), but the vulnerability of short food supply chains mostly arose from the closure of open-air markets, and the lack of skills and logistics to implement e-commerce. Here, some authors call for a high-level mechanization to address the impacts of pandemics on agricultural systems (Timilsina et al., 2020). Roberts and Perez-Horno and Roberts (2020) stated that together with "*collaboration, shorter supply chains, and digitalisation, enabled quick performance adaptation to new regulations and implementation of shared initiatives for collective survival*".

With all this in mind, some researchers have put their focus into short food supply chains, local production and the type of relations generated in these systems (Cappelli and Cini, 2020). For example, several authors have highlighted how small farms and short-chains responded pretty well to the COVID-19 food crisis (Darnhofer, 2020), especially those farms who sell vegetables and fruit boxes directly to consumers (Correra et al., 2020; Kolodinsky et al., 2020; Petetin, 2020) and call for an integration of food democracy into post-pandemics food systems (Petetin, 2020). The need to enhance collaboration has been highlighted both in short (Correra et al., 2020; Roberts and Pérez Horno, 2020) and long supply chains, to build close relationships among all stakeholders, founded on trust and reciprocal collaboration (Roberts and Pérez Horno, 2020). For instance, Matopoulos et al. (2019) show that the development of stronger relationships and commitment within buyer–supplier relationships during the Greek financial crisis in grocery retailing was rewarded through reciprocal risk sharing and additional efforts to maintain strong supply networks in a time of crisis. This was also found by Correra et al. (2020) in the agroecological food chains in Catalonia.

6. Conclusions

In this article we have shown the centrality that food systems play in COVID-19 discussions. Therefore, we argue that a systemic approach to agriculture and food is essential to adequately understand the COVID-19 pandemic, its impacts and potential avenues to prevent potential future similar events. Indeed, a food systems approach is essential to have a broader picture of the relationship of agri-food systems with COVID-19 and their centrality in the pandemics and the derived socio-economic consequences. In other sectors, such as climate change, food systems approaches have allowed to analyse the complex relations of food with climate and understand the central role they play in such discussions (Mbow et al., 2019; Rosenzweig et al., 2020). Moreover, the COVID-19 emergency can help food to regain its centrality in the national political agendas.

Learning from the impacts of the pandemics on food supply chains and food security, the vulnerability of food systems, and the analysis from a food system perspective should contribute to think on actions directed towards increasing the resilience of our food systems to global shocks, such as the COVID-19 pandemics, as well as to reduce the contribution of agri-food systems to EID. From a risk assessment perspective, reducing the risk associated to long-food chains and globalised food systems is indeed required. From a public health perspective, and following a One Health approach, Patterson et al. (2020) call for an integration of agriculture and health policies, so health policies acknowledge the food system as the base of our health system, while agri-food policy recognizes a pre-eminence of human health in decision making. The importance of building strong collaborative buyer–supplier relationships, even in the face of clear market power asymmetries, is also a useful lesson from the COVID-19 crisis. Thus, understanding the ecology of food systems, providing holistic and interdisciplinary approaches and promoting solidarity, collaboration and collective action have all been proposed as needed actions to build sustainable and resilient food systems to shocks, and this is precisely what agroecology offers to food systems.

Therefore, the pandemic might eventually turn out to be a lever to foster transition towards more resilient and sustainable food systems that ensure food and nutrition security in the face of crises (Dron and Kim-Bonbled, 2020). In the words of Torero (2020): "*The pandemic is an opportunity to hit the reset button, with scientists and social scientists playing an important part*". We add that agroecology provides all the required elements to achieve the challenges ahead.

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.

Acknowledgements

Elisa Oteros-Rozas was funded by the Spanish Ministry of Science, Innovation and Universities (IJCI-2017-34334). Marina di Masso was funded by the Spanish Ministry of Science, Innovation and Universities (IJCI-2016-30769) Federica Ravera was funded by the Spanish Ministry of Science, Innovation and Universities (RYC2018-025958-I).

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