Control of Virus Transmission in Food Processing Facilities

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SUMMARY

Facilities processing meat, fish, and vegetables have been the site of large clusters of COVID-19 cases and subsequent food supply chain disruptions. The indoor, cool, and humid environment where employees work in close proximity exacerbates superspreading events. Interventions to improve air flow and hygienic practices, increase worker physical distances, and promote the use of personal protective equipment are supported by experimental and empirical data as preventing transmission of SARS-CoV-2 among employees. These strategies and other operational policies that promote worker health can be used to reduce the transmission of SARS-CoV-2 and other pathogens, including those that may contaminate food, in the food processing environment.

OVERVIEW

Workers in abattoirs and other food processing sectors are at high risk for acquiring a number of occupational illnesses, including those related to repetitive injury, trauma, hearing loss, and communicable diseases. Workers may become infected with bacteria, parasites, and viruses, and food may become contaminated with these pathogens from live animal sources, infected workers, or contact with contaminated equipment or the environment. The risks to agricultural workers of occupational zoonoses (i.e., those diseases transmitted between animals and humans) have been reviewed *(47, 60)*. However, many zoonoses are emerging infectious diseases in humans that do not have livestock or fish reservoirs. Many viruses have a narrow range of hosts, and the maintenance of these viruses in the human population and their transmission in the community and the food processing environment is primarily dependent upon direct human-to-human contact, human fecal-oral transmission under conditions of poor personal hygiene, contact with contaminated objects and aerosols, or airborne transmission. For example, the disease "butchers' warts," caused by a human papilloma virus 7, is found almost exclusively among meat handlers *(38, 41)*. Thus, sanitary controls at slaughter and meat processing are important for both food safety and occupational health. Several large clusters of COVID-19 cases have been associated with traditional food markets in Asia, fish processing facilities in Africa, and large industrialized meat processing facilities in North America and Europe *(Fig. 1)*. These reports have highlighted the vulnerabilities in the food supply chain that can result from widespread illnesses among workers in the food and agriculture sector and subsequent disruptions in trade and the food supply chain.

At first glance, the distribution of human illness caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the virus responsible for COVID-19, was consistent with a food or food-animal reservoir. SARS-CoV-2 tests have yielded positive results from food packaging and the food production environment, but no investigations have linked contaminated food or domestic food animal reservoirs with the transmission of the disease to humans *(10, 20, 24)*. In food processing environments, the prevention and control of transmission of SARS-CoV-2 requires measures to interrupt person-to-person transmission.

Dynamics of disease transmission

The reproductive rate, R_0, of infectious diseases is a helpful metric to describe how easily an infection can spread in a population. R_0 is the average number of susceptible individuals that will become infected through contact with an infected person. For example, the R_0 for SARS-CoV-2 is approximately 3 *(52)*. In contrast, the R_0 of measles, one of the most contagious pathogens, is 12 to 18 *(31)* and that of the 2009 pandemic H1N1 virus was 1.46 in the community and 1.96 in settings where close contact between individuals was common, such as military bases, summer camps, schools, and night clubs *(7)*. When R_0 is <1, outbreaks are predicted to subside. Modification of key behaviors such as adhering to physical distancing, avoiding large gatherings, and wearing face masks to reduce virus transmission can lower the R_0 *(23)*.

Because R_0 represents an average, it does not reflect the dispersion or heterogeneity of transmission in the population. For COVID-19, the transmission of viruses is highly variable *(2, 53)*. A disproportionately small number of individuals are responsible for transmission of the vast majority of new infections that occur under certain circumstances. For example, for SARS-CoV-2 an estimated 10% of infected individuals are responsible for 80% of new infections *(43)*. The occasions when these peaks

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FIGURE 1. Personal protective equipment on workers in a meat packing facility.

of transmission occur are called superspreading events (SSEs). The factors that contribute to SSEs are not yet fully known. However, as more data become available from epidemiological investigations the disease transmission models for SARS-CoV-2 become more robust. As the ability to identify and more accurately predict SSEs increases, steps can be taken to prevent SSEs, thereby reducing disease transmission.

Characterizing SSEs

Large clusters of COVID-19 cases have been reported among workers in meat, vegatable, and fish processing facilities and in other group settings such as assisted living facilities, cruise ships, prisons, parties, bars, weddings, funerals, and religious gatherings *(46)*. High rates of disease transmission at these events can be attributed to the interactions of three primary factors: (i) the pathogen characteristics, (ii) the biology and social behavior of the human hosts, and (iii) the environmental conditions.

Pathogen Characteristics

SARS-CoV-2, like other coronaviruses, is an RNA virus with an outer envelope. The receptor binding domain of the viral spike protein specifically binds to angiotensin-converting enzyme 2 on human host cells, contributing to both the species host range and the tissue predilection in the host body *(75)*. This receptor is present on cells in a variety of tissues and is highly expressed on cells lining the lungs, blood vessels, small intestines, and other organs *(35)*. This distribution helps explain routes of infection virus replication and pathology, and routes of subsequent virus excretion via respiration (e.g., heavy breathing, speaking, cheering, singing, coughing, sneezing, and spitting) and fecal contamination *(56, 76)*.

SARS-CoV-2 is subject to point mutations and genetic recombination *(77)*. Such changes allow for laboratory differentiation between strains recovered during the course of an outbreak and permit the tracking of transmission pathways. Genetic changes can alter the virulence of viruses and their ability to replicate, change host range, or avoid the host immune response. Through continued surveillance and sequencing, it may be possible to identify particular mutations or genetic variants of SARS-CoV-2 that are more frequently associated with SSEs.

In addition to the virus host specificity conferred by the receptor binding domain of the spike protein, presence of the virus envelope is another characteristic that modulates the occurrence of SSEs. Enveloped viruses, such as SARS-CoV-2, are generally less environmentally stable and more susceptible to disinfectants than are non-enveloped viruses *(54)*. Most of the viruses that have been associated with foodborne disease outbreaks are nonenveloped *(66)*. Mutations and genetic recombination do not lead to loss of viral envelopes.

Host

Host factors that influence SSEs can be grouped into two categories: those related to the biological response of the host and those related to host behavior. SARS-CoV-2 particles are expelled from the body in respiratory excretions such as droplets and aerosols and in the feces. The virus load present in these excretions varies among individuals, and superspreaders produce more aerosol particles than do other individuals *(56)*. Other elements contributing to aerosols, emission include the stage of disease, speech volume, and unknown physiological factors *(3)*. The virus can be shed by individuals who remain asymptomatic early during infection, throughout the entire time while infected, or during recovery *(40)*. Fecal shedding of the virus raises the concern of fecal-oral transmission due to inadequate personal hygiene. Asymptomatic shedding of the virus poses a particular challenge for reducing virus transmission because effective control requires that all individuals, even those who may not feel ill, practice virus transmission prevention strategies.

A key contributor to person-to-person transmission is the behavior of infected individuals, especially the proximity of infected individuals within a susceptible population, and the precautions that are taken to prevent disease transmission. Large gatherings are recognized as major drivers of SSEs *(42, 51)*. This hypothesis has been supported by the reduction of new COVID-19 cases following the prohibition of mass gatherings *(4)*. The food processing workplace (for meat, poultry, fish, and vegetables) is no exception, where large numbers of individuals work in close proximity *(17, 18, 32)*. The longer the duration of contact with an infected individual, such as long work shifts, the higher the risk of transmission *(42)*.

The primary route of SARS-CoV-2 transmission is through the direct inhalation of contaminated droplets or aerosolized particles. Indirect transmission acquired by touching contaminated surfaces has been hypothesized based upon detection of viruses on fomites, but this route of transmission has not been documented for SARS-CoV-2 *(26)*. The likelihood of transmission is dependent upon sufficient amounts of virus capable of causing an infection reaching a susceptible host. Factors that influence the amount of virus reaching the next host include the amount of virus (viral load) expulsed, the distance the droplets or aerosolized particles travel, and the viability of the virus when it reaches a susceptible host. Some researchers have hypothesized that individuals exposed to lower viral loads develop milder illness *(25)*.

When the mouth is uncovered, a cough or sneeze may disseminate particles as far as 7 to 8 m, depending upon airflow *(8)*. Even speaking can disseminate particles, and more particles are expelled when speaking loudly, as frequently occurs in the noisy food processing environment *(3)*. Sampling in hospital rooms of COVID-19 patients has revealed widespread environmental contamination, including positive PCR assay results from air sampled 4 m from the patient. However positive PCR test results do not necessarily indicate that infectious virus is present; these assays may yield positive results from inactive virus and nucleic acid fragments. The amount of virus exposure required to result in infection is still unknown *(33)*, and the highly sensitive PCR tests can detect nucleic acids at very low concentrations that may be insufficient or unlikely to result in an infection. Proximity of workers is important during work activities, while entering or exiting a facility, and during breaks and meals. Covering the mouth and nose with a mask can considerably reduce transmission of COVID-19 *(12, 13)*.

Environment

Environmental conditions in modern food processing facilities are conducive to the survival and dissemination of pathogens. Activities, temperature, and humidity impact aerosol formation, droplet size, droplet dissemination, and virus viability. Slaughter and food processing practices often involve large volumes of water for carcass rinsing, flume-based systems used to move and wash produce, and environmental and equipment cleaning. Bioaerosols are an important source of contamination in slaughterhouse environments *(9, 55)*. Airborne transmission is suspected in the spread of avian influenza in live poultry markets *(6)*. Human papillomavirus 120, hepatitis B, and WU polyomavirus (a virus believed to be involved in severe respiratory disease of humans) have been detected in aerosols collected from animal slaughterhouses *(34)*. Given the host specificity of these viruses, the source of the viral DNA detected in the study was presumed to be workers in these facilities. The WU polyomavirus can be aerosolized by coughing or sneezing, but this pathogen and others may also disseminate through splashes during hand washing and facility and equipment *(63, 69)*.

During coughing, sneezing, and speaking, virus are expelled from the lungs in aerosols and droplets of various sizes (0.01 to 500 μm). Larger droplets (>170 μm) quickly drop to the ground within 1 m and are responsible for contamination of the environment and direct exposure to those individuals in close proximity *(28)* *(Fig. 2)*. Smaller droplets, in particular aerosolized particles, can travel farther and be inhaled deeper into the respiratory tract. Under experimental conditions (21 to 23°C, 40% relative humidity), SARS-CoV-2 remained infectious in aerosols for 3 h with only a slight decrease in viral infectivity *(70)*. Relative humidity affects particle evaporation and aggregation and can thus impact both the distance the particles can travel and their trajectory. At higher humidity, such as often found in processing plants, particle size is generally higher and dissemination is reduced *(28)*. The relative contributions of aerosols and droplets in COVID-19 transmission is not fully understood and may be influenced by the host and the environment, but both factors are considered important *(56)*.

The persistence of viral RNA on surfaces is influenced by ambient relative humidity, temperature, and the surface on which it is deposited. Viral RNA was detectable on multiple surfaces (e.g., floors, trash cans, handrails, and doorknobs) in the rooms of COVID-19 patients *(33)*. Under laboratory conditions, predictions indicate that <1% of SARS-CoV-2 in aerosols or deposited on copper remain infectious after 8 h (21 to 23°C, 40% relative humidity), whereas on more

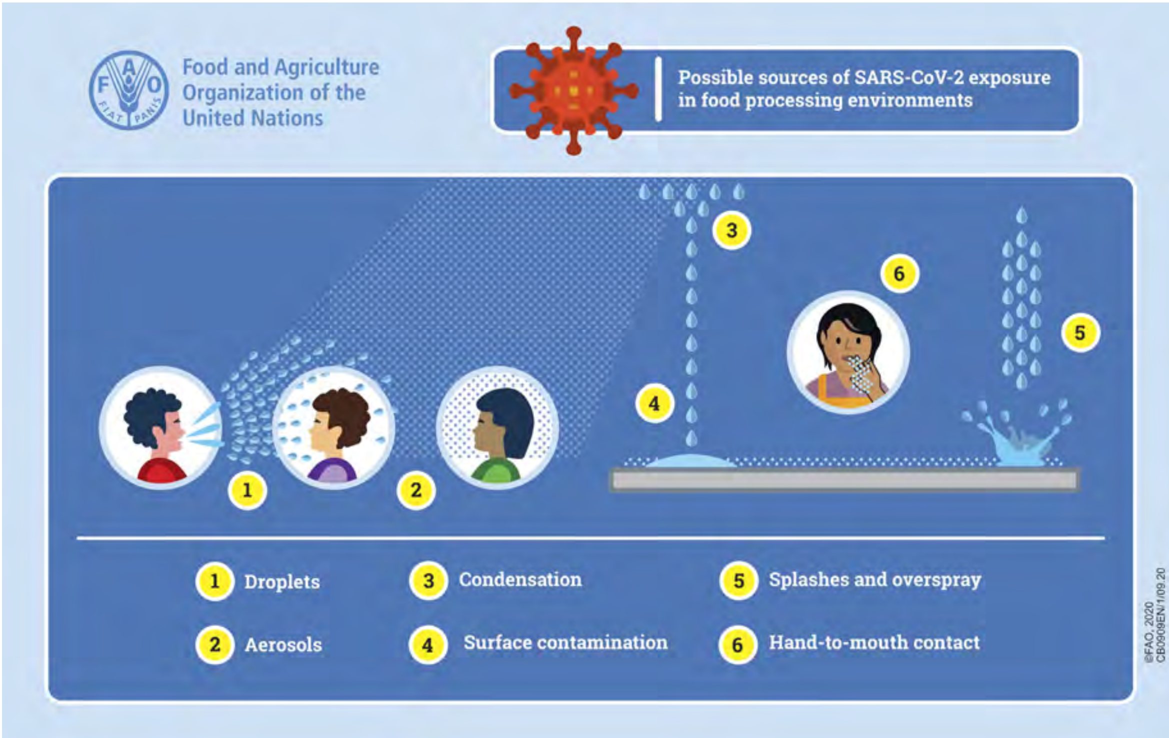

FIGURE 2. Possible sources of SARS-CoV-2 exposure in food processing environments.

porous surfaces such as stainless steel, plastic, and cardboard, 20, 37, and 44%, respectively, of the inoculated virus remains infectious after 8 h. A review of articles evaluating the persistence of other human and veterinary coronaviruses revealed that some viruses can remain infectious for up to 28 days at low temperatures (4°C) and high relative humidity (>50%) *(39)*. Coronaviruses persist at low temperature in high humidity, but high humidity is deleterious to virus persistence at higher temperatures (>20°C) *(1)*. Modern food processing environments are often maintained at low temperatures to control bacterial growth, and humidity is often high. For example, the desired relative humidity for dry aging of beef is 75 to 80% *(16)*. The use of large volumes of water and steam contributes to high humidity and often condensation in food processing environments.

Preventing SSEs in the food processing environment

The probability of acquiring COVID-19 in a food processing plant depends upon the characteristics of the virus, its survival in the environment, the susceptibility of the individual, and the viral load. Although a number of anthropogenic factors such as population structure, antimicrobial use, and vaccination can drive pathogen evolution *(45)*, food business operators have limited direct or immediate control over the natural evolution of the virus infectivity and pathogenicity. Various host factors (e.g., diabetes, hypertension, and smoking) have been proposed as associated with disease susceptibility and severity *(21, 71)*. In the long term, promotion of good health among employees and the availability of adequate health insurance and sick leave can reduce predisposing risk factors for food processing workers and may reduce the likelihood of employees becoming seriously ill, and in turn, reducing the risk of infecting other employees.

In food businesses, managers, supervisors, and workers all can decrease the dose of SARS-CoV-2 to which employees are exposed. Methods for separating workers and preventing COVID-19 SSEs can be structural, mechanical, or operational. Adoption of control strategies may be influenced by factors such as product safety and quality, economic constraints, and socio-behavioral drivers *(18)*. Interventions should be applied in food processing areas and all other areas of the facility were people are in close quarters such as breakrooms, washrooms, locker rooms, administrative offices, and company-provided housing.

Mechanical controls

The phenomenon of the SSE is primarily one of indoor environments *(46)*. Control of virus transmission and persistence within a food processing environment is therefore critical. SARS-CoV-2 infection primarily results from inhalation of the virus but can occur from inoculation of the lips or eyes by droplets or aerosols or by touching the nose, mouth, or eyes with a contaminated hand *(59)*. Structural or mechanical engineering designs that reduce the survival or dissemination of the virus will reduce the potential for transmission. Examples of such control strategies include sufficient air exchange, directional airflow that forces air away and down to prevent contaminated air from passing by the faces of adjacent workers, and air filtration and disinfection processes *(58)*. Poor air circulation has been associated with disease transmission *(48)*, and air recirculation should be avoided.

Structural partitioning between workers

Physical barriers have been suggested for partitioning worker space and reducing direct transmission of viruses in food retail and meat packing facilities *(61, 65)*. Although reports documenting the effectiveness of such interventions in the food processing environment have yet to be published, use of barriers is supported by current understanding of droplet dissemination and the use of similar interventions to prevent the infection of health care workers in contact with COVID-19 patients. Experimental models have indicated that use of plastic drapes or acrylic boxes to separate medical personnel from coughing patients greatly reduces the potential amount of contamination for the exposed staff *(44)*.

Facial coverings and gloves

Face masks may provide some protection to the wearer *(25)*, but the primary goal of face mask use in the food processing environment is to provide a physical barrier to limit the spread of the virus from an infected individual to another person and to the surrounding food production environment. Despite initial conflicting recommendations on the use of facial coverings in various settings *(11)*, the preponderance of current evidence supports their use in the food production environment *(36)*. The type of face mask, material from which it is constructed, frequency of replacement, and most importantly, correct placement and compliance with use protocols will impact the effectiveness of face masks for preventing disease transmission. Masks of most commonly used materials, providing they are several layers thick, are capable of preventing the transmission of most virus-laden droplets and some of the larger aerosol particles *(36)*. One review of recent trials indicated that N95 respirators were not better than medical masks for protection from virus infections *(5)*.

Face shields and eye protection are recommend personal protective equipment for health care workers and cleaning personnel in hospitals with COVID-19 patients *(73)* and have been suggested by others as a possible adjunct to face masks for preventing community-acquired SARS-CoV-2 infections *(62)*. Experimental studies have indicated that face shields can reduce inhalation of >95% of influenza virus particles contained in aerosols of a median 8.5 µm diameter immediately after expulsion but were less effective 30 min after a cough, reducing exposure by only 23% *(50)*. No clinical trials have been reported on the efficacy of face shields or goggles for reducing exposure to SARS-CoV-2.

Disposable gloves are commonly used in the food processing environment to prevent contamination of food, but their use outside the health care setting specifically for COVID-19 control has not been evaluated *(19)*. Glove use in food processing can lead to complacency, a false sense of security, and a decrease in hand washing activities *(68)*.

Materials used in equipment and food contact surfaces

Structures, equipment, and food contact surfaces in food processing facilities should be constructed from materials that are easily cleaned and sanitized. In general, coronaviruses remain infectious longer on porous surfaces (e.g., cardboard, wood, and clothing) than on non-porous substrates such as glass, plastic, polyvinylchloride (PVC), ceramic, stainless steel, zinc or aluminum, with the shortest survival on copper, copper nickel, and brass *(1)*.

Operational controls

Supplemental operational controls can complement physical barriers to virus dissemination and may be more easily implemented than structural changes to facilities. Paramount among factors contributing to disease transmission is the distance between infected and susceptible individuals. Operational controls may include instituting one-way traffic flows, staggering start and break times, and decreasing throughput to decrease the number individuals needed to work on a line at a given time.

Physical distancing

Although SARS-CoV-2 may be spread by aerosol particles, when droplets are expelled by infected individuals most of the heavier particles fall to the ground within 1 m *(28)*. A meta-analysis revealed that those individuals >1 m from the source were far less likely to become infected than were those <1 m away, an effect that increased as distance increased *(12)*. Spacing work stations as far as possible from one another can reduce virus transmission. The same principle would apply to break rooms, lockers, cafeterias, and other locations where employees congregate.

Temporal distancing

Another option that can be used to reduce the density of employees working in close proximity is to stager shifts, start times, stop times, and breaks. Changes to the working hours can reduce the congestion of individuals in entryways, exits, locker rooms, or break rooms.

Symptom screening and exclusion

The most effective way to reduce transmission of SARS-CoV-2 in food processing facilities is to exclude infected individuals from the work site effectively reducing those that may act as sources of infection. Screening for COVID-19 symptoms has been used for identifying infected travelers and has been recommended for use in the food industry *(64)*. However, the process has limitations associated with asymptomatic carriage of the virus, test performance, and attempts by individuals to conceal symptoms *(27)* because of unpaid or inadequate sick leave or fear of retribution for missed work. Fever (body temperature >37.3°C) *(74)* is not always present in COVID-19 patients, especially early in the infection. The prevalence of fever as a symptom among COVID-19 cases ranges greatly, with some estimates of 20% *(30, 57)*. Gostic et al. *(27)* estimated that temperature screening would fail to detect half of the COVID-19 cases at airports, primarily because of asymptomatic carriage, but these authors emphasized the need for effective and prompt case contact tracing, another tool that should be applied to exclude potentially infected workers from food processing facilities. Thus, although temperature screening has poor sensitivity, it may be valuable for identifying a portion of infected employees.

Hygiene and sanitation

Personal hygiene and environmental sanitation are the basis for prevention of food contamination and production of safe food. Essential principles of food hygiene have been outlined in many texts and have been published in the *General Principles of Food Hygiene* (CXS1-1969) by the Codex Alimentarius Commission *(13)*. The *Guidelines on the Application of General Principles of Food Hygiene to the Control of Viruses in Food* (CAC/GL 79-2012) and other commodity-specific codes of practice from the Codex Alimentarius *(14, 15)* provide information applicable for the control of SARS-CoV-2, although the focus of these documents is primarily the protection of food from contamination. Because humans can contaminate equipment, food contact surfaces, and floors with SARS-CoV-2, the principles of cleaning and sanitizing should be followed for the decontamination of these items, thus reducing the potential of employees contracting COVID-19 following contact with contaminated surfaces. Care should be taken when undertaking cleaning procedures, and particular attention should be paid to avoid the generation of aerosols or dissemination of virus from contaminated surfaces. Pressure washing in food facilities can aerosolize and distribute contaminants for several meters *(67)*. Education and refresher training of employees in appropriate hygiene and sanitation practices may lead to improved compliance with best practices.

Because of the potential for self-inoculation with SARS-CoV-2 by touching the face with a contaminated hand, hand washing is critical and should be frequent, especially after toileting, before eating, and any time after touching potentially contaminated surfaces. However, hand washing also may contribute to splash or cross-contamination from sinks and the surrounding environment *(22, 29)*. Fortunately, SARS-CoV-2 has no unique resistance to disinfectants and is susceptible to biocidal agents commonly used in the food processing environment *(37)*. Because of potential contamination of the food production environment, cleaning procedures may need to conducted more often *(18)*.

Limitations

A hierarchy of interventions based on their effectiveness for the control of occupational hazards has been proposed, with elimination of pathogens from the work environment as the most effective, structural (engineering) and operational (administrative) controls as less effective, and the use of personal protective equipment as the least effective *(65)*. However, this proposed ranking is not specific for food processing environments and does not consider the feasibility or practicality of proposed control measures. Many of the strategies for COVID-19 control are based on extrapolations of data on SARS-CoV-2 or similar organisms but in other environments, such as the health care sector. Limited data are available on the efficacy and practicality or feasibility of these interventions in the food processing environment. The experimental or epidemiological evidence collected under different conditions are location independent (e.g., efficacy of masks to prevent transmission from patients) and are supported by sound scientific inference. Application of similar interventions to the food processing environment are thus predicted to be equally effective. Under the conditions of food processing, mandatory mask wearing and possibly face shields or eye protection may be one of the most effective options based on feasibility and cost.

Food quality, food safety, economic, and sociobehavioral considerations may preclude or limit the adoption of some of the control measures suggested here. For example, high humidity and low temperatures are required in meat coolers for food safety and to prevent product desiccation. Increased air filtration and disinfection may require investment in equipment and structural changes to a facility. Improved airflow and ventilation may require additional. may require additional energy to cool incoming outside air. Physical distancing of workers may require decreased line speeds or product throughput. Enhanced or increased cleaning and sanitation cycles require more person-hours. These expenses should be viewed as investments in worker safety and occupational health.

Company policies should not penalize employees who do not report to work while sick and should not incentivize workers to work when they are feeling ill. Training should be provided on safe practices such as proper mask-wearing, physical distancing, and sanitary practices. In many countries, food processing jobs are filled by immigrants who may not be fluent in the first language of the business. All employees must receive reliable information and training about COVID-19 in formats and languages that can be understood *(49)*. Awareness, training, and education are critical but must be followed by adoption of preventive practices, that is, changes in management or behavior required to prevent SARS-CoV-2 transmission.

CONCLUSIONS

To date, SARS-CoV-2 has not been isolated from food-producing animals, and food has not been directly implicated in the transmission of the disease. The challenges posed by COVID-19 to the food industry are primarily associated with occupational health and disruptions in supply chains. Identifying and interrupting the factors that contribute to SSEs between humans, which are associated with crowded places including food processing facilities, is critical for the design of optimal disease control programs *(72)*. Targeting intervention strategies at the small fraction (10%) of the potential SSEs and locations responsible for the majority (80%) of new cases can mitigate SARS-CoV-2 transmission in the community, including at food processing facilities, which are known superspreading hot spots. Prevention of these diseases will strengthen the food supply chain.

In general, control strategies focus on reducing the transmission of SARS-CoV-2 by excluding sick workers, erecting physical barriers between work stations, requiring face protection, and aerosol generation, and enhancing sanitation to prevent virus transmission. Providing training and applying these principles in all food processing environments (fish, meat, dairy, and produce) will reduce the transmission of SARS-CoV-2 and limit the spread of other pathogens, thereby keeping workers healthy and the food supply safe.

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