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Review

Improvement strategies of food supply chain through novel food processing technologies during COVID-19 pandemic

Bimal Chitrakar [a], Min Zhang [a,b,*], Bhesh Bhandari [c]

[a] State Key Laboratory of Food Science and Technology, Jiangnan University, 214122, Wuxi, Jiangsu, China
[b] International Joint Laboratory on Food Safety, Jiangnan University, 214122, Wuxi, Jiangsu, China
[c] School of Agriculture and Food Sciences, The University of Queensland, Brisbane, QLD, 4072, Australia

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ABSTRACT

Coronavirus disease-19 (COVID-19) is a contagious disease caused by a novel corona virus (SARS-CoV-2). No medical intervention has yet succeeded, though vaccine success is expected soon. However, it may take months or years to reach the vaccine to the whole population of the world. Therefore, the technological preparedness is worth to discuss for the smooth running of food processing activities. We have explained the impact of the COVID-19 pandemic on the food supply chain (FSC) and then discussed the technological interventions to overcome these impacts. The novel and smart technologies during food processing to minimize human-to-human and human-to-food contact were compiled. The potential virus-decontamination technologies were also discussed. Finally, we concluded that these technologies would make food processing activities smarter, which would ultimately help to run the FSC smoothly during COVID-19 pandemic.

1. Introduction

COVID-19 is an infectious disease caused by a novel coronavirus, called severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) (Huang et al., 2020). Wuhan (the capital of Hubei province) was the epicenter, where the first case was reported in December 2019. It was spread to other parts of China and then to the rest of the world at an escalating rate. By March 11, 2020 the World Health Organization (WHO) officially announced COVID-19 outbreak as a global pandemic (Cucinotta & Vanelli, 2020). The major mode of transmission of this virus is thought to be person-to-person via the tiny droplets from the infected person during breathing, sneezing or coughing. These droplets landing on food surfaces, food packages or objects like door knobs, elevator switches etc. is believed to remain on these surfaces for some time, depending upon the temperature and the nature of the surfaces. These viruses can be transmitted to humans by touching these surfaces and then touching the nose, the eyes or the mouth (Mahmoud, 2020). Therefore, it is strongly recommended to wash or to disinfect one's hand regularly and not to touch the nose, the eyes and the mouth without hand washing during worktime (NHM, 2020).

Researchers are now working hard to understand the epidemiology and biology of SARS-CoV-2 for the vaccine development and some success news about the vaccine seems to be in near future: Even after the start of the vaccination, it may take years for its availability for the world. During the early stages of pandemic, as no solid medical interventions were successful, resulting a threaten to human lives (Anwar et al., 2020), different drugs were studied for their possibilities, including heparin (Hippensteel et al., 2020) and remdesivir (Beigel et al., 2020). So, the WHO has introduced non-pharmaceutical measures to minimize its spread, including the avoidance of social gathering and outdoor activities, lockdown and travel restriction, and the use of personal protective gears (Nicola et al., 2020; WHO, 2020). Such interventions were found highly successful in China, South Korea, and Singapore within a short period of time, which made other countries to follow the same methods at the maximum possible level (Shahidi, 2020). However, most of the countries have been struggling to curb the spread of this virus from several months with a little success.

Medicals, foods, and groceries are allowed their services, considering them as essentials during a lockdown period. But, the fear of the viral infection and the movement restriction highly affected food-related activities, including pre-harvest agriculture, post-harvest processing, and distribution. The panic of food shortage resulted in the stockpiling of foods, which caused the temporary stock-out in the market. A survey in the USA showed that grocery shopping was their highest priority

* Corresponding author. School of Food Science and Technology, Jiangnan University, 214122, Wuxi, Jiangsu, China.
E-mail address: min@jiangnan.edu.cn (M. Zhang).

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(>90%) during the COVID-19 lockdown (Fig. 1), indicating food was the most prioritized thing after medication. It is worth to mention some statements about the importance of food during the COVID-19 pandemic:

> *"Without food, there can be no exit from the pandemic."*- Torero, M., The chief economist of FAO (Torero, 2020);

> *"We need to act now to stop this health crisis transforming into food crisis."*- Gilbert F. Houngbo, President of IFAD (IFAD, 2020);

> *"Policy makers around the world need to be careful not to repeat the mistakes made during the 2007–08 food crisis."* (FAO, 2020b);

The WHO, FAO, CDC and European food safety authority have ruled out the transmission of coronavirus through food and packaging, possibly due to the virus being lower heat stable (≤70 °C) and unstable in outside environments (Mahmoud, 2020). However, the origin of this outbreak being from the Wuhan wet-market and an outbreak from the Xinfadi wet-market in Beijing have raised the question that if foods, especially meat products can be a carrier (MailOnline, 2020). Two more outbreaks were reported – meat processing plant in Germany (Arens, 2020) and seafood processing plants in China (Tencentnews, 2020). Moreover, the detection of this virus on the packages and the interior wall of the containers, carrying frozen shrimp (NetEase, 2020) and the positive virus test in frozen chicken wings (Pei, 2020) indicated that the virus can survive longer in cold conditions. These consequences are threats to the people working in food processing plants, resulting in a possible disruption of their work. The limit in outdoor activities plus restriction in transport and travel also causes the shortage of labor and input supplies, which affects activities in the food supply chain, viz. harvesting, processing, and distributing, with a possibility of a food crisis. The ready-to-harvest fresh products cannot reach to the market destinations, causing the spoilage in the farms, which results in temporary short-supply and long-term food shortage. Therefore, proper measures need to be taken for smooth running of food supply chains, using various technologies to overcome these consequences. This paper was designed to understand the impact of COVID-19 pandemic on food supply chains (FSC) and discuss the novel technologies applicable in food processing arena to assure its smooth running during such pandemic.

2. Food supply chain (FSC)

A food supply chain (FSC) refers to all the processes that describe how foods from farms end up on our tables, including farming, processing, distributing, retailing, and consuming (Fig. 2A) (Siche, 2020). The FSC can be divided into two parts, namely the supply and the demand: The supply side involves farming, harvesting, processing, and distribution, which need a time-bound action to achieve optimum quality foods, whereas the demand side includes customers, whose economy as well as the abiotic and biotic conditions, such as drought, flood, ecological disturbances, and the COVID-19 like pandemic are the influencing factors.

A study on the effect of the COVID-19 on food supply chain was conducted by using the flexibility of a model fresh produce supply chain (onion), based on the real option theory and described the food supply chain resilience in terms of its flexibility (Chenarides et al., 2020). It was found that the fast-moving consumer goods (FMCG) were more resilient than fresh produces during COVID-19 pandemic. Furthermore, they found that the US food supply chain experienced critical weaknesses during COVID-19 pandemic with the lack of resilience in the supply chain, which indicated the lack of flexibility in supply chain management, rather than a market failure. Therefore, the switching option and switching cost were the paramount parameters, which might appear negative in the absence of switching option (Chenarides et al., 2020). Similarly, Hobbs (2020) assessed the impact of the COVID-19 pandemic on food supply chain and its resilience on the disturbance in transportation, and labor shortage as well as the shocks on demand-side, including consumer panic purchase behavior, and the changes in food consumption patterns from the food serving installments to home-prepared foods.

The FSC can be explained as a complex network of various components, which are dependent on different sub-components (Transportation, labor and inputs) as shown in a network diagram (Fig. 2B). The following section deals with the impact of COVID-19 pandemic on these sub-components.

2.1. Impact of COVID-19 pandemic on transportation

Transportation is one of the issues that makes the FSC moves forward, which links all the components. Various forms of transportation are available, including bulk sea freight, rail transport, marine containers, truck transport, and home delivery service. The staples use bulk

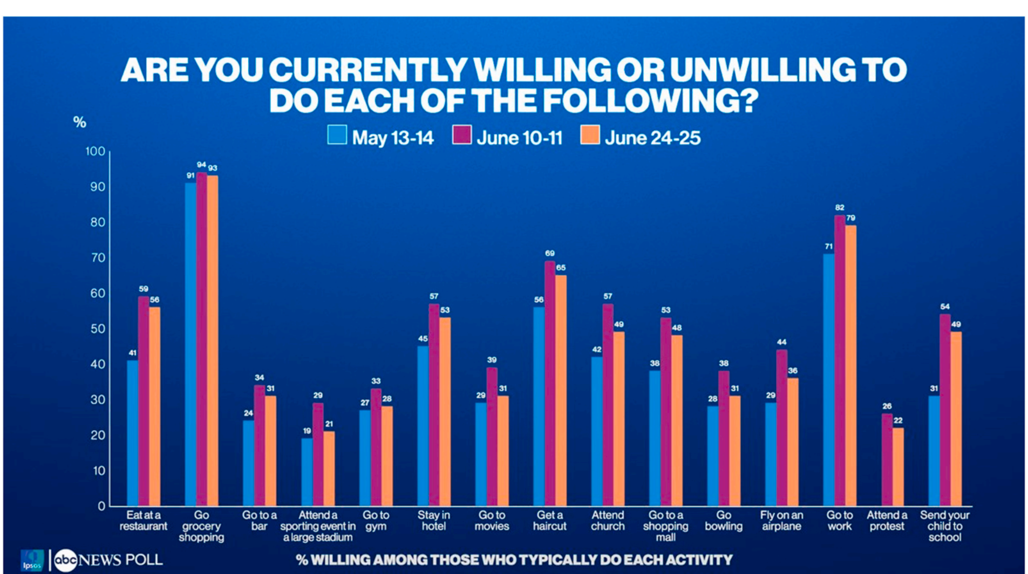

Fig. 1. Activities that people willing to do during lockdown (abcNEWS, 2020).

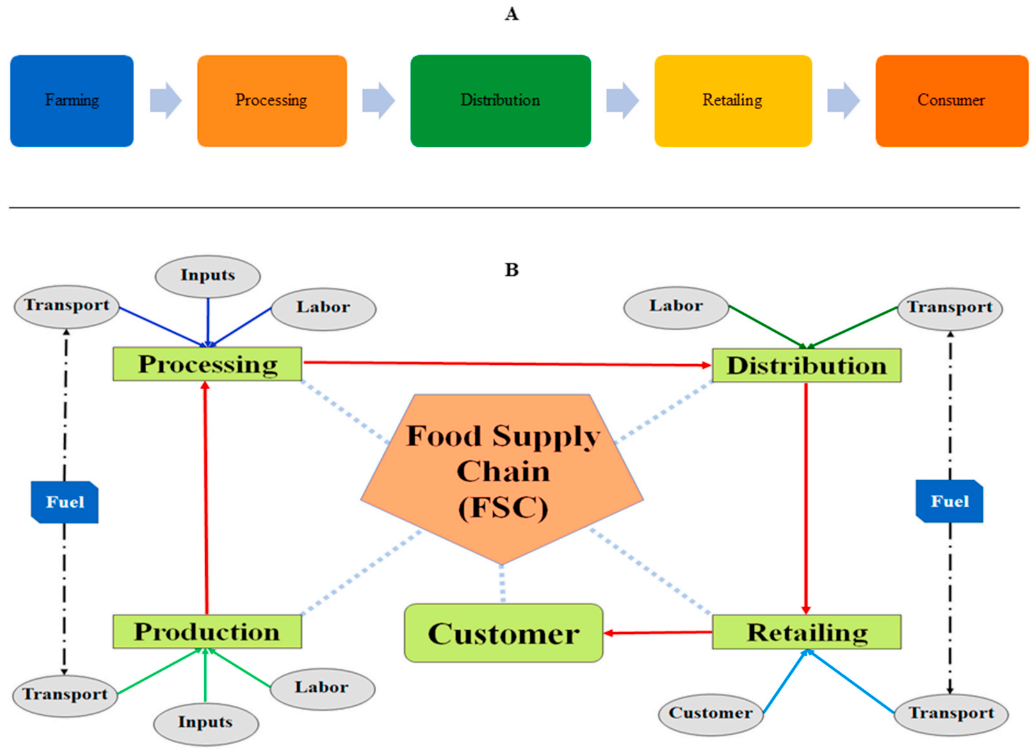

Fig. 2. (A) Activities in a simple food supply chain (FSC); (B) Various components and sub-components in a food supply chain network.

sea freight, rail transport, heavy containers and trucking, whereas perishable products rely on refrigerated containers or air freight for longer distance and refrigerated trucks for shorter distance. Home delivery service is for local level short distance transport (Gray, 2020).

The COVID-19 pandemic has abruptly impacted transportation because of the lockdown, which include restricted travel and transportation. The sea freight was found available for food sector due to the limited demand for other sectors, as evident from the lowest decrease in the Baltic Exchange Dry Index in May 2020 (The peak time of global lockdown). Rail transport is less labor-intensive and the reduction in non-food transports creates more availability for food during the COVID-19 pandemic. However, the quarantine requirement of the marine containers for 14 days at the port during the COVID-19 pandemic may cause a container shortage. The use of truck transport is in a relatively good position to quickly respond to the COVID-19 related disruptions in the food supply chains as the transportation of other goods are slowed down during this period (Gray, 2020). But, the truck drivers in Canada faced the lack of enough access to toilets because of the shutdown or reduction in opening hours of roadside restaurants (CBC, 2020). Additionally, the COVID-19 lockdown made restaurants and bars stop their table service, which escalated pickup and home delivery services (Gray, 2020). The authors have experienced and made use of more online food delivery systems during COVID-19 pandemic in China.

The damage caused by the restriction in transportation is mainly due to the lack of transfer of ready-to-sell goods to their destinations. During the initial 21 days of lockdown in India, the dumped products include six tractors of grapes, and tomatoes and 1500 L of milk (Nandi & Swamikannu, 2020). Milk dumping was reported also in the USA (Forstadt, 2020) and Nepal (NepaliSansar, 2020). Such disturbance was also seen in Bangladesh (Roy, 2020), resulting in the down-price of fish products (Zabir et al., 2020), daily unsold milk amounted to 27,000 tons (Bashar & Atik, 2020) and chicken and eggs sales decreased to 75% (Rajalakshmi, 2020). These are few examples only; the amounts not reported are expected to be much higher.

2.2. *Impact of the COVID-19 pandemic on labor availability*

Farming and food processing are labor-intensive; a huge number of labor forces are required to run them, which is fulfilled by migrant workers. For example, the USA and Canada depends on Mexican workers for their agriculture industries, covering one-third of such jobs. More than 60,000 Mexican seasonal workers enter to Canada for agro-industries. The cross-border restriction of Mexican labors to the USA and Canada affected the farming and processing industries (Richards & Rickard, 2020). Labor shortage was also seen in India (Nandi & Swamikannu, 2020), Bangladesh (Zabir et al., 2020), and China (Zhang, 2020) due to travel restriction. Such consequence in India was predicted to affect the upcoming spring crops like corn, sunflower, canola, vegetables (Singh, 2020), and fish farming (FAO, 2020a), with an uncertainty of the future supply of these crops.

2.3. *Impact of the COVID-19 pandemic on inputs supply*

Agricultural inputs include seeds, fertilizer, and agro-chemicals, vaccines, medicines, and cleaning chemicals. Fish farming requires fishing gear, fish feeds, and medicines. For food processing industries, other ingredients, packaging materials, fuel, cleaning materials, and additives are vital inputs. During COVID-19 pandemic, transportation restriction, closure of industries, and boarder closures all affected input supplies (Aday & Aday, 2020). Moreover, some of these materials are categorized in non-essential under the lockdown protocol.

3. Technological intervention to reduce the impact of COVID-19 on the FSC

Foods are the second most prioritized things after medication during the COVID-19 pandemic. Therefore, food availability and accessibility are the major issues raised due to the restriction protocols imposed (de Paulo Farias & dos Santos Gomes, 2020). This section discusses in detail about food processing by the novel and smart technologies to avoid human-to-human and human-to-food contacts at the maximum possible levels. Our aim is to replace human effort by these smart technologies so that the tasks are accomplished with minimal human contact. Below is the compilation of applicable technologies available so far in food processing.

3.1. Smart packaging technology

Modified atmosphere packaging (MAP) and Active packaging (AP) have been widely used to increase the storage life of fresh foods (Qiu et al., 2019). During COVID-19 pandemic, packaging is more important for making food safe to use and for keeping it fresh for longer transportation delays caused by lockdown. MAP technology consists of modifying the gas composition inside a package to extend the shelf-life through limited metabolic, microbial, and enzymatic activities (Rennie & Sunjka, 2017). The gas composition inside the package is modified and maintained by introducing defined composite gas (Badillo & Segura-Ponce, 2020). In some instances, the respiratory rate of the fresh products inside the MAP is so high that the permeability of the material is insufficient to transport CO_2 and O_2, causing an anaerobic environment for anaerobic spoilage (Larsen & Liland, 2013). Perforated packaging was designed for such consequences with adequate numbers and size (Kartal et al., 2012; Ozdemir et al., 2005). The use of MAP to extend the shelf life of different products with storage temperature and gas composition are listed in Table 1.

Active MAP is a one-step forward approach to keep the products inside the packaging sound, safe, and wholesome, where an inclusion of an active compound helps the absorption or release of substances to prolong the product shelf-life (Yildirim et al., 2018). Table 2 lists the examples of active MAP with storage temperature, gas composition and active compounds used.

The most advancement in MAP is the incorporation of intelligent technology, where the use of indicators detects the chemical changes due to the microbial growth. These indicators include smart labels, sensors, radiofrequency identification tags, time-temperature integrator (TTI), security tags etc. (Zhang et al., 2015). For example, polyaniline film was used to monitor the freshness of fish (Kuswandi et al., 2012), whereas TTIs were used to indicate the safety and quality of ground beef and spiced cooked chicken (Ellouze & Augustin, 2010), fresh foods (Riva et al., 2001), "golden drop" (a Thai dessert) (Nopwinyuwong et al., 2010), and mushroom (Bobelyn et al., 2006). Additionally, the development of packaging materials with anti-SARS-CoV-2 properties, as hypothesized with copper, zinc and silver nanoparticles containing polymers (Sportelli et al., 2020), would be an interesting area of development because they were reported to act against hepatitis A virus and human norovirus (Randazzo et al., 2018).

Table 1
Use of MAP in various food products to extend the shelf-life.

Food products	Shelf-life, days	Temperature (°C)/gas composition	References
Sliced cooked ham	44	7 °C/%N_2: %CO_2 = 45:55 to 80:20	Raimondi et al. (2019)
Fresh fig	15	5 °C with irradiation/5% O_2, 10% CO_2, 85% N_2	Waghmare and Annapure (2018)
Fresh hake fillet	3/6	1–7 °C/N_2:CO_2 = 50:50	Antunes-Rohling et al. (2019)
Strawberry	10	4 °C/2.5% O_2 + 10% CO_2	Zhang et al. (2006)
Blueberry	35	5 °C/40–100% O_2 ventilated	Zheng et al. (2008)
Jackfruit cuts	35	6 °C/Flush with 3 kPa O_2 + 5 kPa CO_2	Saxena et al. (2008)
Broccoli	35	3, 4, 13 °C/%O_2:%CO_2 = 3:8, 5:5 and 5:10 (balance with N_2)	Tano et al. (2007)
Green asparagus	20	2 °C/Flush with 10 kPa O_2 + 5 kPa CO_2	An et al. (2006)
Fresh pork	8	4 °C/5–55% O_2 and 20% CO_2 (balance with N_2)	Zhang and Shrestha (2005)
Buffalo meat	15	4 °C/80% O_2 + 20% CO_2	Sekar et al. (2006)
Beef muscle	15	4 °C/0–80% O_2 + 20% CO_2 (balance with N_2)	Zakrys et al. (2008)
Salmon fillet	14	4 °C/60% CO_2 + 40% N_2	Pettersen et al. (2011)
Scallops	21	6 and 20 °C/10% O_2 + 30–75% CO_2 (balance with N_2)	Simpson et al. (2007)

Table 2
Active MAP in various food products to extend shelf-life.

Products	Shelf-life, days	Temp	Gas composition/Active compound	References
Chicken breast	15	4 °C	30% CO_2 + 70% N_2/Allyl isothiocyanate	Shin et al. (2010)
Lamb meat	14	4 °C	%CO_2: %N_2 = 60:40 and 80:20/Thyme or oregano essential oils	Karabagias et al. (2011)
Sea bream	28	4 °C	40% CO_2, 30% O_2, and 30% N_2/Oregano essential oil	Goulas and Kontominas (2007)
Ready-to-eat iceberg lettuce	5	4 °C	Air at 95% RH/Eugenol, carvacrol, and *trans*-anethole	Wieczyńska and Cavoski (2018)
Pre-baked buns	13	RT	Normal air/Ethicap (an ethanol emitter)	Franke et al. (2002)
Bakery products	28	25 °C	%CO_2:%N_2 = 30:70 and 0:100/Oxygen absorber	Guynot et al. (2003)
Egg-based dessert	20	RT	60% CO_2 + 40% N_2 Oxygen absorber	Suppakul et al. (2016)
Ready-to-eat chicken breast	60	4 °C	High-pressure processing/Coriander essential oil	Stratakos et al. (2015)
Ready-to-eat poultry	10	8 °C	Normal air/ZnO nanoparticles	Akbar and Anal (2014)

3.2. Smart freezing and thawing technology

Freezing preservation majorly involves freezing, frozen storage, and thawing, to retain the fresh-like properties of foods. The conventional freezing is carried out by air-blast-, immersion-, fluidized bed-, and cryogenic-freezing, whereas the novel freezing uses ultrasound, ultra-high pressure, pulsed electric field, ultra-low temperature, high-voltage electrostatic field, and radio-frequency (Wu et al., 2017). The monitoring and detection of freezing and other food processing activities can be done by smart technologies for its mechanization and automation. They include electronic nose, electronic tongue, nuclear magnetic resonance, near infrared spectroscopy, hyperspectral imaging, computer vision, and artificial intelligence (Xu et al., 2017), which are discussed in the following section.

3.3. Smart monitoring technology

The use of smart technologies for processing monitoring, without direct involvement of human resources is a need for the COVID-19 pandemic period. The environmental factors including temperature, relative humidity, CO_2, ethylene, and gas composition in the package are required. Temperature monitoring is given the utmost importance because quality degradation majorly depends on temperature exposure, storage time, gas constant, and activation energy (Labuza et al., 2003). Relative humidity is another parameter, which determines the freshness of food products; a system was tested to measure it in a package by using an autofocus sensor, where data was transmitted through radio transmission (Hübert & Lang, 2012).

For the monitoring of O_2 and CO_2 concentration inside a package, an intelligent monitoring and control system was developed with the sensors, linked with a digital converter analog for data acquisition, where the control was done by a single chip microcomputer using fuzzy logic (Liu et al., 2005). Similarly, Borchert et al. (2013) developed a color-based CO_2 sensor using phosphorescent Platinum-porphyrin dye, linked to the Förster Resonance Energy Transfer (FRET) system.

A real-time freshness monitoring was done by ethylene concentration through the use of tin oxide (SiO_2) gas sensors (Giberti et al., 2004), and molybdenum (Mo) chromophores color sensor (Lang & Hubert, 2012). Similarly, hydrogen sulfide produced by lactic acid bacteria, *Clostridium* and other pathogens in meat (Eeckhaut et al., 2012; Kalinowski & Tompkin, 1999) and fish (Serio et al., 2014) was detected through a myoglobin- (Smolander et al., 2002) or a copper acetate-based (Koskela et al., 2015) sensors. Moreover, total volatile basic-nitrogen from animal protein breakdown, can be detected using bromocresol green based pH sensors (Pacquit et al., 2006) and polyaniline film-based sensor (Kuswandi et al., 2012).

3.4. Smart detection system

The inspection of quality throughout the food processing to avoid deviation and to take corrective action against the deviation has been practiced using various means, including human sensory organs and advanced smart technologies. This section deals with the online smart detection technologies, which minimize the direct human involvement for the smooth running of food processing during COVID-19 pandemic.

3.4.1. Smart odor detection - electronic nose (E-nose)

An E-nose is a simulated human nose for sensing odors, which is based on bionic olfaction to detect the complex odors through the array of gas sensors, including metal-oxide semiconductor, quartz-crystal microbalance, and surface-acoustic waves (Wilson, 2012). An E-nose was successfully applied for food spoilage detection (Casalinuovo et al., 2006), meat and fish freshness assessment (Hasan et al., 2012), pineapple shelf-life estimation (Torri et al., 2010), and green tea grading (Yu et al., 2008). Similarly, the adulteration of pork in mutton mince (Tian et al., 2013), differentiation of rice varieties (Zheng et al., 2009), and discrimination of fish species (Güney & Atasoy, 2015) were also accomplished by E-nose. The details of its principles, methods, applications, and recent advances in its uses in food sectors were recently reviewed by many researchers (Mohd Ali et al., 2020; Shi et al., 2018; Tan & Xu, 2020). Since E-nose is relatively faster, and less destructive, it can be used for real-time odor detection without direct human involvement.

3.4.2. Smart taste detection – electronic tongue (E-tongue)

An E-tongue is a simulation of the human tongue for rapid, and unbiased detection of five basic tastes via taste sensors, including potentiometric sensors, voltametric sensors, and bioelectric sensors (Jiang et al., 2018). Potentiometric E-tongue has been used for oil classification from a single olive cultivar (Dias et al., 2014), honey differentiation (Escriche et al., 2012), beer and wine discrimination (Nery & Kubota, 2016), and sugar quantification in solution (Arca et al., 2019). Similarly, voltametric E-tongue was used to detect the adulteration of sunflower oil in argan oil (Bougrini et al., 2014), to discriminate the honey from different flowers (Tiwari et al., 2013), and to analyze spring water (Carbó et al., 2017). Last but not least, bioelectric E-tongue was employed to analyze the biocide residues (Malvano et al., 2017) and toxins (Solanki et al., 2010; Srivastava et al., 2014) in foods. Bioelectric sensors were also employed to detect the growth of bacteria, especially food pathogens, such as *E. coli* O157:H7 (Lin et al., 2019), *Salmonella typhimurium* (Sheikhzadeh et al., 2016), *Staphylococcus aureus* and *Bacillus cereus* (Reich et al., 2017). Such an intelligent determination technique without direct involvement of human makes it an ideal technique suitable during the COVID-19 pandemic. The details of its principles and applications in food sectors for various purposes can be viewed in recent reviews (Jiang et al., 2018; Tan & Xu, 2020).

3.4.3. Smart moisture detection - LF NMR and MRI systems

The determination of moisture and water activity in a food is vital for its safe keeping. The conventional methods are time-consuming, and destructive, whereas low field nuclear magnetic resonance (LF-NMR) and magnetic resonance imaging (MRI) are nuclear magnetism based powerful tools for rapid and descriptive analysis without requiring sample destruction (Kirtil & Oztop, 2016). A real-time monitoring of moisture content and its distribution were reported during the drying of abalone (Song et al., 2017), corn (Lv et al., 2018), vegetables (Lv et al., 2017), and shitake mushroom (Cheng, Li, et al., 2020; Zhao et al., 2019). Moreover, we have recently reported the intelligent detection of the safe level of water activity (0.6) through the use of LF-NMR during the drying of vegetables and fruits (Chitrakar et al., 2019, 2020). These magnetic resonance technologies have been deployed to monitor other processes, including pre-brining and freezing of shrimps (Gudjónsdóttir et al., 2011), the fermentation process (Kreyenschulte et al., 2015; Ramanjooloo et al., 2009), and to determine the internal quality of apples (Chayaprasert & Stroshine, 2005), the blackheart in pomegranates (Zhang & McCarthy, 2012), the bruising in fruits and vegetables (Du et al., 2020), moisture status and migration during refrigerated storage of beef (Cheng, Wang, et al., 2020), multiple freeze-thaw cycles in beef (Cheng et al., 2018), total lipids and bound lipids in oats (Li et al., 2020), and oil species identification (Hou et al., 2019). The details of its principles and applications can be viewed from recent reviews (Ezeanaka et al., 2019; Kirtil & Oztop, 2016).

3.4.4. Smart near infra-red spectroscopy (NIRS)

The NIRS can be used for the determination of carbohydrates, fats, proteins, water etc. in food without requiring sample preparation and sample destruction. Kawamura et al. (2007) developed a model using NIRS for online detection of lactose, fat, protein, urea nitrogen, and somatic cells in milk. Models were also developed for the determination of soluble solids in citrus fruits (Wang & Xie, 2014) and watermelon (Jie et al., 2014), pigment content in cream (Zhang et al., 2020), botanical origin of honey (Zhao et al., 2011), and food safety hazards (Fu & Ying, 2016). Moreover, Beghi et al. (2014) estimated the storage life of cold-stored apples. However, the use of NIRS is still at the laboratory scale and its industrial scale-up needs to be developed for its online detection (Wang et al., 2018). The details of its principles, and applications along with its limitations on online applications were already reviewed (Porep et al., 2015).

3.4.5. Smart hyperspectral imaging system (HIS) technology

An HIS technology is the integration among spectroscopy, chemometrics, and imaging technologies, giving special data and signals simultaneously (Ma et al., 2019). It gives reliable and accurate information about the structure, composition, physicochemical-, and sensory-properties at a faster rate without requiring sample preparation and direct human involvement. Moreover, it is suitable for heterogenous materials as well. The use of an HSI technology in fruits and vegetables, legumes and cereals, meat, dairy and eggs has been reported (Siche et al., 2016) for the evaluation of biological contaminants in food, including viable microorganisms and their toxins and insect infestation and parasitic contaminations (Vejarano et al., 2017). Moreover, physicochemical properties determination, real-time process monitoring, freshness and defect detection (Ma et al., 2019) as well as Aflatoxins classification (Xing et al., 2019) were also reported by using HSI technology. In addition, researchers have shown it to be a promising real-time technology for online detection of quality and safety of foods (Baiano, 2017; Khan et al., 2020).

3.4.6. Smart computer vision technology

Computer vision is a rapid and non-destructive technology, giving consistent and accurate results, which processes the images received from an image acquisition system. It was applied for real-time monitoring during drying of food products (Aghbashlo et al., 2014). The combination of this technology with e-nose and e-tongue was found to succeed the real-time monitoring of odor and taste, respectively

(Ghasemi-Varnamkhasti et al., 2010). It can evaluate the differences between samples or the different regions within a sample with the help of algorithms and a computer system. Its wide applications has already been tested in different foods for various purposes; the details of their uses in these sectors were reviewed by (Ma et al., 2016) and (Wu & Sun, 2013).

3.4.7. Artificial intelligence (AI) technology

Artificial Intelligence (AI) is one of many novel smart technologies, which can replace human effort for object recognition with the help of computer vision technology (Cohen & Feigenbaum, 1982). AI uses numerous data points available on the web by the use of two major systems, called Neural Networks (NN), and Deep Learning to attain an outstanding performance (Russell & Norvig, 2020) through the modern computational power, called Graphics Processing Units, which makes it possible for NN to imitate the human brain to solve the complex tasks (Macedonia, 2003).

The NN based electronic nose system was successfully employed to discriminate the aroma of honey (Benedetti et al., 2004) and tea (Borah et al., 2008), with classification accuracy of more than 90%. The AI was used for grading of coffee beans (de Oliveira et al., 2016) and eggs (Omid et al., 2013), with respective accuracy of 100% and 95.4%. The artificial NN plus computer vision was employed for color- and size-classification of beans, with the performance accuracy of 90.6% (Kılıç et al., 2007). Therefore, it can be concluded that AI techniques can be employed in various food processing sectors; the scope of which is expected to increase in post-COVID period (Kakani et al., 2020) to address the customer expectation to have minimal human-to-human and human-to-food contact during food processing.

3.5. Potential technologies for virus decontamination

During the COVID-19 pandemic, the customers feel a panic and threat of virus contamination in the purchased foods and packaging, which can be largely eliminated through the use of various technologies, such as cold plasma, UV and mild heat treatment (Darnell et al., 2004; Filipić et al., 2020). Cold plasma treatment was found effective against viruses on food surfaces, such as fresh meat (Bae et al., 2015), lettuce (Aboubakr et al., 2020; Min et al., 2016), and blueberries (Lacombe et al., 2017). Virus inactivation and pathogen destruction (*E. coli* O157: H7, *Salmonella*, and *Listeria monocytogenes*) was reported for cold plasma (Roh et al., 2020) as well as UV treatment (*E. coli*, *Klebsiella pneumonia*, and *Candida albicans*) (Heßling et al., 2020). Additionally, a mild-heat treatment (65 °C for 4 min) and UV-C (254 nm) treatment (15 min at pH > 12 or <3, 25 or 37 °C) can be another alternative (Darnell et al., 2004). An advanced oxidation process, where a combination of UV-C along with ozone, H_2O_2, Cu etc. at very lower concentrations than that would be effective if used individually, giving nearly 600% virucidal effect was also reported (Quintel et al., 2019).

The use of nano-based antimicrobial particles in facemask, gloves, and aprons can be another promising technology. Copper and silver nanoparticles, which show antiviral properties against influenza virus, which can be incorporated in cotton (Kanovsky, 2016), and polyesters (Clement, 2008) for such purposes. TiO_2- or Ag-nanoparticle based disinfectants to clean buildings (StatNano, 2020) and food processing surface coating by anti-SARS-CoV-2 nanoparticles (study has started from September 2020 and will finish by April 30, 2021) (Brockgreitens, 2020) were recently reported. The use of nanoparticles in packaging materials to get the antiviral properties has been already discussed elsewhere in this manuscript. However, the nanomaterials showing possible side effects on human health (skin irritation, allergy or toxicity) and possible environmental contamination with nanomaterials are to be considered for their large-scale and long-term use.

4. Challenges and limitations

During a pandemic like COVID-19, the demand of technological innovation is higher than ever. However, the technological interventions may face many challenges and limitations. The major challenges include the economic and feasibility challenges such as the lack of infrastructure, technical knowhow, and adaptational capability. Moreover, the novel coronavirus is new to the world and scientific studies are still young to know about this virus. Though it was said that food was unlikely to be a medium to transmit the virus, new cases are popping-up, including the case of 1553 COVID-19 positive workers in Tönnies Meat Processing Company, Germany (Arens, 2020) as well as the case of a sea-food processing workers in Dalian Kaiyang Seafood Company, China (Tencentnews, 2020). Moreover, an outbreak in the Beijing Xinfadi Wet Market infecting 329 people (the outbreak was suspected from the salmon-cutting chopping board) (MailOnline, 2020) and the recent finding of the virus on the interior wall of the vehicle container and outside of the packaging of frozen shrimp in China (NetEase, 2020), have forced us to think about the technological preparedness to use these smart technologies, which avoid human-to-human and human-to-food contact during food processing. The presence of the virus on the packaging and the container wall showed that the virus can survive on a surface and can last for longer at a lower temperature. Previous coronavirus, such as SARS-CoV and MERS-CoV were found to remain infectious for 2 years at −20 °C (BfR, Bundesinstitut für Risikobewertung 2020). However, SARS-CoV-2 was reported to remain viable on stainless-steel and plastic surfaces for 2 and 3 days, respectively and on copper and cardboard surfaces for 4 and 24, respectively at 21 °C and 40% RH (van Doremalen et al., 2020). It is also suggested that the chances of SARS-CoV-2 virus transmission through the foods from infected animals or cross-contamination cannot be overruled (Oakenfull & Wilson, 2020, pp. 1–21). Therefore, the technological interventions to guarantee the avoidance of human contacts during food processing, packaging, storage, and transportation are the most seeking innovations at this time of crisis.

5. Concluding remarks – about vaccine information?

COVID-19 is a highly infectious disease; the disease is transmitted from person to person via droplets or by touching surfaces, where the virus landed and then entered our body through our nose, mouth and/or eye. Regarding vaccine study, the third phase trials were successfully conducted in the diversified population from South Africa, Brazil, and the UK for its efficiency (Folegatti et al., 2020). Till date, vaccination programs have been in place using vaccines from different companies, including Pfizer, Moderna (CDC, 2021), Astrazeneca and Johnson & Johnson (WebMD, 2021), Sinovac, and Gamaleya (BBC, 2021) with various levels of effectiveness (62–95%) and requiring different storage temperature (2 to −80 °C). The front-line workers are the most prioritized for vaccination at the beginning; therefore, the availability of the vaccine to the whole world population may take years. Therefore, physical means are the means to curb the spread of this virus and technological preparedness to run the food processing activities smoothly are most seeking innovation at present. Food being the second most prioritized issue after medication during the COVID-19 pandemic, agricultural practices and food processing must be efficient for smooth running of the FSC. The food sector is the most labor-intensive one and human-to-human contact is inevitable unless smart technologies are in place. Food processing activities should be mechanized and automated by the use of novel smart technologies so that the direct human involvements are the least possible. The technologies mentioned in this paper are the most recent smart technologies that can be implemented to intervene the impact of the COVID-19 pandemic on food processing, which ultimately impact the food supply chain.

Author contributions

Bimal Chitrakar conducted the literature collection, drafted the manuscript, and compiled data into tables. Min Zhang suggested the original idea of this work and revised the technical contents of the manuscript. Bhesh Bhandari did the revision for its technical contents as well as language correction.

Declaration of competing interest

The authors declare no conflict of interest on the contents of this paper.

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