DOI: https://doi.org/10.21323/2414-438X-2022-7-3-142-149

Available online at https://www.meatjournal.ru/jour
Review article
Open Access

Received 01.08.2022
Accepted in revised 16.08.2022
Accepted for publication 29.08.2022

MANAGEMENT OF FOOD COLD CHAINS TRACEABILITY AMID THE COVID-19 PANDEMIC

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Keywords: *continuous cold chain, COVID-19 pandemic, supply of perishable food, meat and meat food products*

Abstract
The present article considers the functioning of food supply chains and their major component — a continuous cold chain of perishable food products, including meat products, under the conditions of COVID-19 pandemic. The issues of the impact of the pandemic on production, processing and commercial supply of meat and meat products in Russia and worldwide are being considered. The traceability of temperature fluctuations in meat processing plants is relevant; it becomes an increasingly important factor for efficient logistics to provide the best supply and to keep the food safe in the current conditions. Research data is presented here. The results of the research show that frozen foods serve as carriers and distributors of SARS-CoV-2 infection without any contact between people. This conclusion highlights additional challenges in controlling the spread of COVID-19 worldwide, and reveals the mechanism of the disease transmission, taking into account the peculiarities of temperature modes during storage and transportation of perishable meat products. The risks of food cold chains functioning under the conditions of pandemic, the adaptive strategies for their mitigation and logistical systems of tracking are considered, in particular, the application of various data technologies.

For citation: Gorbunova, N.A., Kornienko, V.N. (2022). Management of food cold chains traceability amid the COVID-19 pandemic. *Theory and Practice of Meat Processing,* 7(3), 142-149. https://doi.org/10.21323/2414-438X-2022-7-3-142-149

***Funding*:**
The article was published as part of the research topic No. FGUS-2022-0014 of the state assignment of the V. M. Gorbatov Federal Research Center for Food Systems of RAS.

Introduction

Continuous cold chains (CCC) serve to maintain the quality and safety of highly perishable food (HPF) while delivering it from the producer to the consumer while reducing the loss of raw materials of [1,2]. Studies show that the efficiency of CCC is often lower than the perfect one due to violations of the required temperature modes used for storage and transportation of the particular product, which deviation endangers the health of the consumer [3,4].

The concepts of the continuity of the “cold chain” of low temperature storage modes and the traceability of the “temperature history” of the HPF are the main characteristics of CCC for food, and especially for meat products. The lack of control and records of temperature at any of its main or auxiliary stages of delivery or storage can adversely affect the safety of the HPF and thus may prevent the timely withdrawal of poor-quality food products [3,5,6].

The importance of the efficient functioning of CCC for HPF was proven, among other things, by the global COVID-19 pandemic, since the survival of coronavirus 2 of severe acute respiratory syndrome of (SARS-CoV-2) predominantly depends on the ambient temperature [7,8,9].

The COVID-19 pandemic has also put an unprecedented load on the food supply chain (FSC), having revealed the weak points in its major stage, i. e. CCC, that impose challenges for agricultural food producers and suppliers (especially HPF) at the stages of its processing, storage and transportation, as well as significant changes in demand and logistics of HPF distribution.

As a rule, food supply chains, including CCC, are associated with various activities, people, materials, information, financial resources, knowledge and skills, which serve as the building bricks, which need to be managed within the FSC (Figure 1). Three important attributes of FSC, that determine its performance, are: adaptability, consistency and flexibility. The most efficient FSCs make it possible to detect structural shifts and violations, sometimes before they occur, by collecting data in “real time mode”, filtering out the external influences and tracking key patterns [7].

In our interconnected and interdependent world, the management and traceability of all stages of FSC, including food refrigeration (CCC), is essential to identify the potential long-term impacts of the pandemic, and ensure food safety and human health.

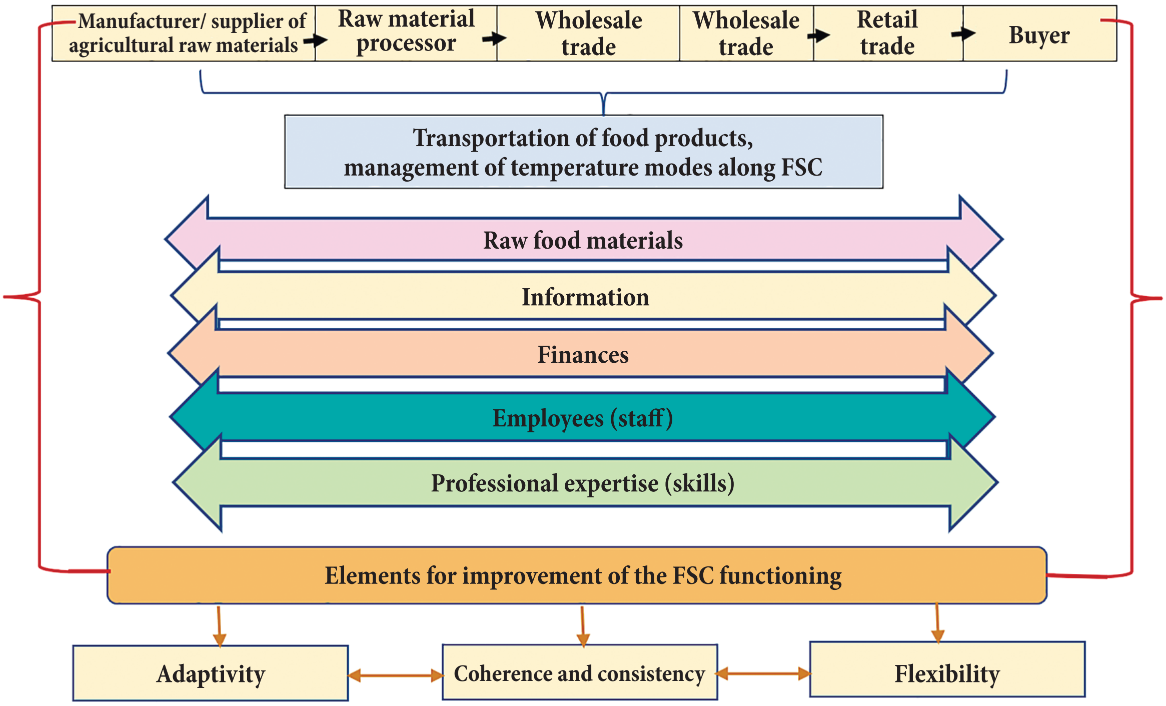

Figure 1. Mutual correlation of FSC elements

Impact of COVID-19 on meat food production and supply chain

The processing chain of agricultural products in a number of countries under the conditions of COVID-19 was disrupted due to the introduction of social distancing rules, labor shortages caused by disease, quarantine measures to restrain the spread of the virus, etc. It should be noted that not all sectors of the agro-industrial complex and types of products were affected by the pandemic in equal degree. Highly perishable food products suffered the greatest failures at various stages of the CCC.

The meat industry in developed countries has been seriously affected — the links between processing of raw material, production and supply of meat products has been disrupted due to restrictions imposed by governments of numerous countries [10,11]. In addition, meat processing appears to be more pandemic-sensitive than other food industries, in particular due to the labor-consuming nature of food processing operations [10,11]. The outbreaks of Covid-19 among production personnel in meat processing plants (MPs) have been reported in a number of countries, including the United States of America, Canada, Brazil and Europe [12,13].

The impact of COVID-19 on meat production and meat products supply chain is shown below in the Figure 2 [14].

Usually, the employees of a meat-processing plant work together, literally "side by side" in a cold and damp environment, which can facilitate the spread of the virus. This way of virus distribution was indirectly confirmed by the temporary closure of meat-processing plants (MPP) due to severe outbreaks of diseases among the employees. These outbreaks seriously disrupted the supply chain of livestock and meat [12].

For example, at french MPPs in some regions of the country, most affected by COVID-19, the number of working employees decreased by 30% [15]. In the United States of America, the slaughter of cattle and pigs in April 2020 decreased by about 40% in comparison with the same period in 2019 due to low demand of MPPs for livestock [16]. The impact of MPPs closure in 2020 was particularly pronounced in North America due to high concentration of this industry, because almost 60% of pork processing capacities in US are covered by 15 MPPs only [17]. The loss of production capacity has reached 25–43% in the USA [18].

Studies of the impact of the COVID-19 pandemic on the meat production sector in America and Brazil have shown its incredibly destructive and devastating effect on meat processing, especially during April and May 2020, caused by the outbreak of the virus in slaughterhouses, which led to extraordinary increase in livestock prices. Beef processors encountered a decline in beef production compared to January-March of 2020, by 21% in April and 19% in May; pork production declined by 18% and 19% in April and May, respectively.

During the last week of April and the first week of May, 2020, U.S. daily beef and pork processing volumes fell down about 40% below the levels of 2019. It is also noted that for the two-month period from early April to early June 2020, federally controlled cattle slaughter volumes were on average 22% lower than in the same period in 2019, while pig slaughter decreased by 13%, compared to the previous year [19]. In Canada 75% of beef processing plants were shut down due to slaughterhouse closures, especially in Alberta province.

The study [20] highlighted the impact of COVID-19 on the price of beef in the USA. The first surge of price increases was mainly caused by the effects of the quarantine,

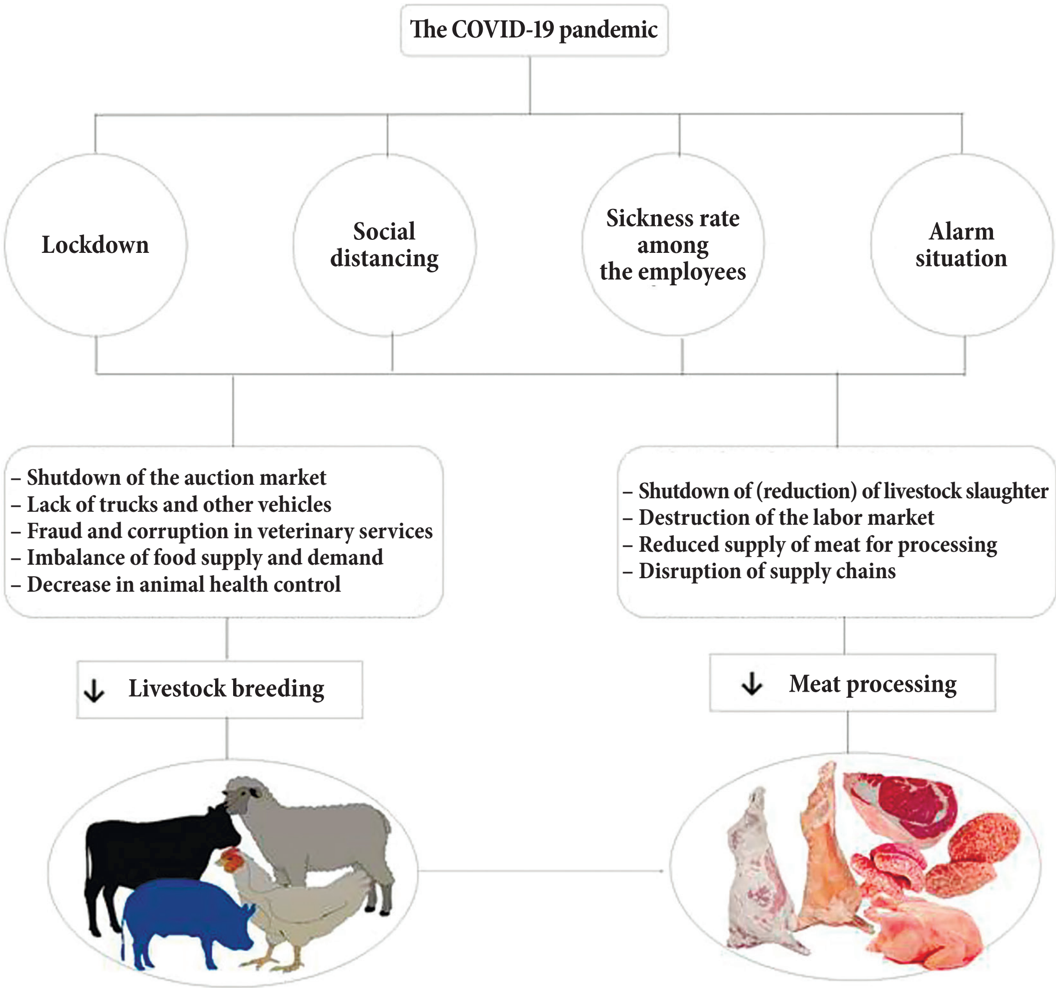

Figure 2. Impact of COVID-19 on meat production and supply chain [14]

held from March 06 to April 10, 2020 (the prices increased up to 39.1%), especially for boneless beef cuts, widely used in the production of ground beef, due to increased demand. On the contrary, the price of, for example, ribs and tenderloin decreased by up to 42% due to the wide closure of diners and eateries. The second surge of prices (April 10 to May 08, 2020) was more pronounced due to a reduction in beef production, which led to a 150% increase in boneless cuts prices. By the end of March 2020 in the United States of America, the wholesale meat prices jumped more than 1.2 times in comparison with March prices. This increase in prices was mainly caused by the widespread concern, which provoked a panic among consumers, which in its turn led to an increase in demand in grocery stores. The wholesale price for beef kept rising, thus reaching the highest recorded price of USD459 per ton of beef on May 15, 2020 due to reduced meat production and the shutdown of MPPs [21].

In the Russian Federation, as of May 2020, more than 50% of manufacturers declared financial losses. Only 47% of surveyed companies in various regions of the country showed no negative financial result for April 2020, while 53% showed a significant loss from 1 to 50 million rubles. The situation of regional meat producers is more complicated than at the federal level. 75% of the surveyed federal players show a positive financial result (25% of them showed slightly negative result), while regional producers feel absolutely opposite — more than 69% of them suffered from negative financial result as of April 2020. Experts recognize HoReCa the most affected sales channel — as it is a wholesale trade sector and specialized meat stores and shops, developed by many local producers [22].

Taking into account the impact of the COVID-19 pandemic, the Ministry of Agriculture of the Russian Federation lowered the forecast for level of agricultural production. According to the Ministry's assessment, presented in the National Report on results of implementation of the state program for agriculture development, the increase in the agro-industrial complex was reduced from 1.8 to 1.0% in 2020 [23].

The initial estimated impact of the pandemic on the meat industry accounts for about 13.6 billion USD, while additional impacts are highly likely to occur in the future [24]. For example, a possible impact of the COVID-19 pandemic on the meat industry is a change in the habitual diet of a part of the population: people may change their diet to consumption of more plant products against the backdrop of a decrease in consumption of animal products due to disruption of the FCS, rush demand and rising prices for meat. [25].

The availability of meat and meat products for consumers is an important and socially significant task, aimed to reduce the consequences of those devastating pandemic situations. For implementation of this social task, it is necessary to ensure the continuity of meat production and the efficient functioning of CCC as part of FCS, without violating the required temperature modes in order to maintain the quality and safety of the HPF.

Traceability of risks in food CCC during the pandemic and the adaptive strategies to mitigate the risks

The pandemic creates a whole range of uncertainties for the food industry, not only because of its uncertain duration and serious consequences. The economic downturn and unemployment caused by the pandemic significantly decrease the consumers' incomes, which could lead to lower demand and cause substitution among the food categories (i. e. substitute costly food with cheaper substitutes). Therefore, an important condition for the efficient functioning of the FSC in the medium and long term, especially under conditions of social uncertainty, is FSC adaptability.

The other main source of uncertainty for FSC is the possibility of recommencement of quarantines in areas exposed to COVID-19 and other infectious diseases, like monkeypox. Where these quarantines require the closure of food service outlets, their FSC face further failures and disruptions. This script was observed during the second wave of the pandemic since autumn 2020 till 2021, when regional and national lockdowns were reintroduced in an attempt to slow the spread of the virus.

The study of the key strategies for FSC organizing has shown that new methods for ensuring their flexibility and sustainable development can play a dominant role in optimization of food CCC after the pandemic [26]. At the same time, the CCC of food products has special features of temperature modes for HPF storage. Those temperature modes differ from the parameters of ambient temperatures, which are typical for the general FSC.

Food CCC plays a dual role in the context of the COVID-19 pandemic: on the one hand, it helps to ensure food safety and reduce the loss of HPF, and on the other hand, it increases the risk of transmission of COVID-19 due to low temperatures modes.

Several incidents have shown that food at CCC stages can serve as carriers of SARS-CoV-2, including over long distances. For example, the earliest known case of transportation of refrigerated SARS-CoV-2 infected food occurred on June 12, 2020 at the Xinfadi Agricultural Wholesale Market in Beijing, China, where they found a cutting board used to process the imported salmon. This cutting board was infected with SARS-CoV-2. Since July 2020, cases of SARS-CoV-2RNA infection from frozen food imported from countries with an ongoing epidemic have been reported in nine provinces of China [27]. The contaminated food and food packaging imported from areas with active SARS-CoV-2 outbreaks served as the potential sources of COVID-19 outbreaks in previously clear, unreported areas, where not a single case of the disease was recorded for several periods (months) according to an assessment report from New Zealand, Vietnam and China [28].

However, the correlation between temperature and spread of COVID-19 remains unclear and controversial. Thus, researches in 62 Chinese cities found that temperatures rising did not mitigate the COVID-19 epidemic [29], and a study of daily cases of COVID-19 infection in 8 countries found that meteorological factors did not significantly affect the spread of COVID-19 [30].

Meanwhile, several research groups have reported that meteorological conditions yet do influence the spread of COVID-19 [9,31]. Thus, a study of the correlation between infection spread and environmental temperature parameters in 166 countries (excluding China) proved that daily temperature increase for only 1 °C was accompanied with a reduction in the daily number of new COVID cases (by 3.08%) and reduction of daily mortality (by 1.19%) [32].

The impact of temperature on spread of SARS-CoV-2 through surfaces of food and commodities in the CCC was studied too. As a result, it was found that SARS-CoV-2 is able to survive for more than 21 days during HRF storage and transportation at temperatures down to minus 18 °C [33].

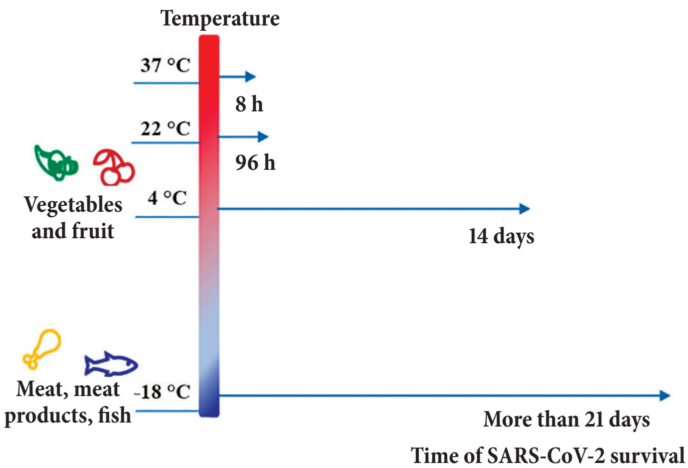

Figure 3. Survival time of SARS-CoV-2 at storage temperatures required for various foods in CCC [34]

The systematic arrangement of the results of assessment of time of SARS-CoV-2 survival on the surface of food at different temperatures shows that SARS-CoV-2 is more likely to be transported through the CCC stages on the surface of frozen meat / fish products compared to fruits and vegetables (Figure 3) [34]. Thus, CCC management practices based on appropriate classification of risks are important to effectively and efficiently reduce the risk of SARS-CoV-2 transmission in FSC.

The results of the analysis of the situation with COVID-19 by foreign researchers show that the future waves of the pandemic (or future pandemics) increase the probability of failures and disruptions for food industry enterprises due to sporadic outbreaks of diseases in their workplaces [12,35].

However, unlike the situation in early spring 2020, there was an opportunity to develop and adapt various preventive procedures afterwards. Thus, the implementation of sanitary and hygienic measures and social distancing at MPPs reduce the risk of infection spread among operation employees, thus helping to protect the health and well-being of workers.

Additional adaptive strategies include automation, robotization and digitalization of production.

The cost-effectiveness of increasing the automation level will depend on the extent to which robotics increases plants productivity, improves quality control, and reduces food safety risks. The pandemic may have contributed a new concern: at the labour-intensive MPPs the production lines should run at slower speeds both to protect worker health and prevent significant loss of revenue should production be interrupted or suspended due to the employees' sickness [15].

Digitization in the FSC is an ongoing trend that can be accelerated by the pandemic also. Technologies that facilitate contactless electronic transactions compared to hard-copies ones are becoming increasingly attractive for population. The development of common standards, for example for exchange of customs data or data on traceability of the goods, can facilitate transactions in cross-border FSC. The System GS1 is an example of a common data standard related to the goods identification, using bar codes, exchanging electronic messages for data collection and their synchronization. The Australian meat industry has developed "MeatMessaging" system basing on GS1 standards as a means of communicating the necessary information about meat products supplied for export. This information enables regulators to verify the authenticity and traceability of meat food [18].

On the territory of the Russian Federation there is a unified information system "VetIS", developed by the Rosselkhoznadzor (RSKhN) in order to create a unified electronic document management system based on digital technologies [36]. It includes several interconnected private systems, including the "Mercury" system, which provides registration of the veterinary examination results and drawing of veterinary accompanying documents; the "VESTA" system, which allows keeping records of laboratory tests, and the other data systems (Figure 4).

Inclusion of the component "Traceability of the HPF temperature modes history" into the "VetIS" system, using the technologies of ERA — Glonass for information monitoring and transmitting, will allow the participants of

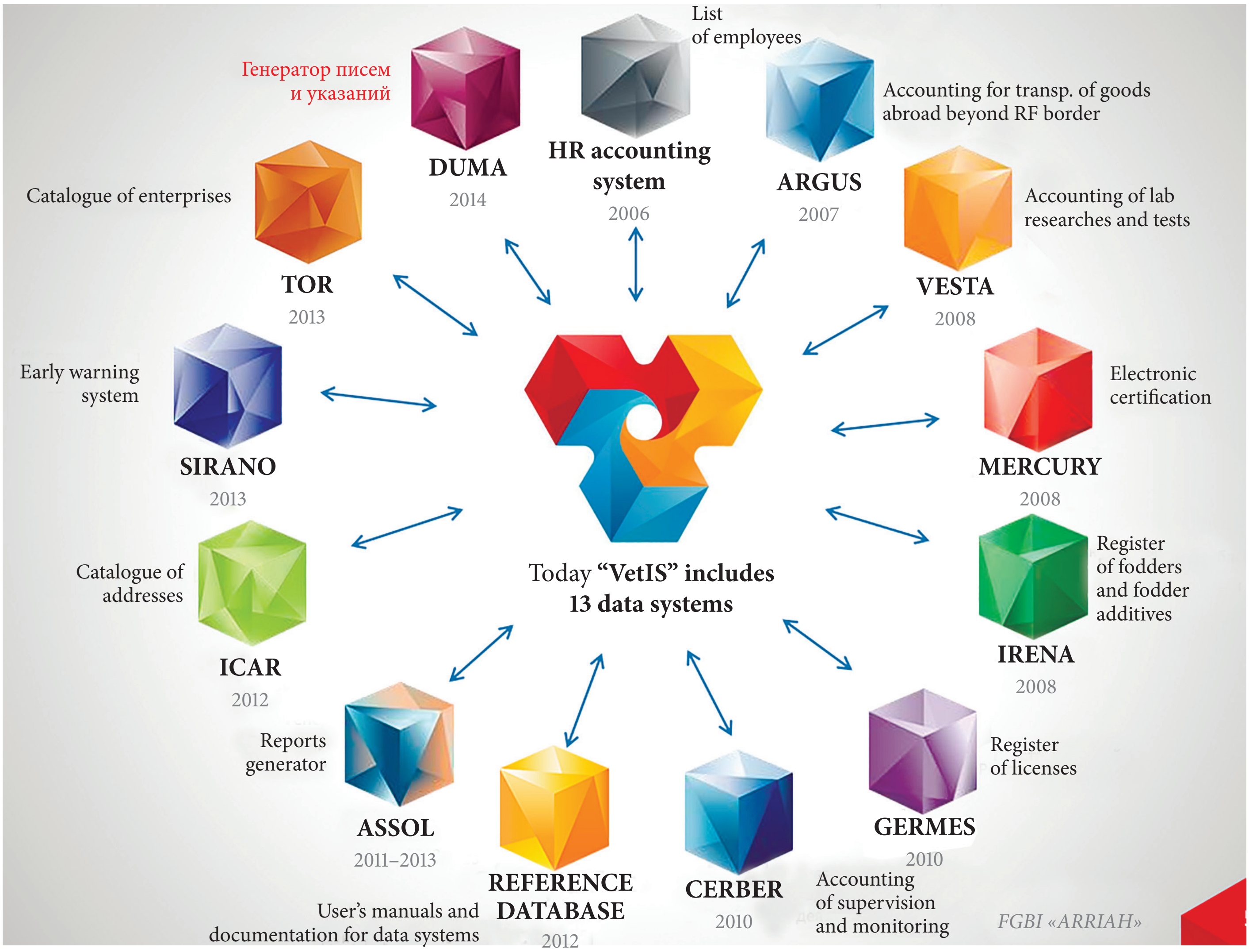

Figure 4. The composition of the information system "VetIS" [36]

the FSC and regulatory authorities receiving data on the actual temperature of the food product when it is exposed to CCC. And in case of violations of the established temperature modes it enables to take proactive measures in order to reduce the risks of food spoilage [37].

The technologies that facilitate transactions in the FSC are likely to be developed further due to increased attention to their resilience and sustainability amid the pandemic. For example, the application of blockchain technology in agricultural food data systems is of increasing interest, because it enables verification of information (including its authenticity), increases food traceability and transparency in the FSC [38–41].

The technology of blockchain is a distributed ledger where transactions are recorded in chronological order to create permanent, unlawful access-secured records between multiple stakeholders [42]. The important point is that once data is added to the blockchain, it cannot be changed by subsequent FSC participants. Therefore, the data that makes up these records must be generated and scientifically validated in order for the blockchain to be useful in facilitating the traceability of food in case of food safety issues, thereby reducing the scale of a problem.

Blockchain technology [43] is not an universal remedy, its application will not be able to prevent fraud with the initial data in the FSC, will not prevent adulteration of food raw materials and distortion of other information, and will not help to eliminate other potential failures in the FSC, for example, a shortage of labor.

The question of whether blockchain technology can increase the responsiveness and resilience of the FSC to external impacts like COVID-19 by increasing the level of interaction within the FSC still remains unsolved. Where FSC bottlenecks arise due to paperwork delays or fragmented procedures, the application of blockchain technologies facilitates the automation of organizational processes and optimizes information flows [42]. The benefits of blockchain in relation to the pandemic are largely to improve the logistics of the FSC (CCC) and improve the cooperation of supply chain participants in case of supply disruptions.

Modern FSCs require breakthrough solutions to increase efficiency and reduce risk. Since the CCC is a segment of the FSC related to products that require strict and continuous temperature control, blockchain technology provides significant advantages for its efficient operation in terms of "temperature modes history" traceability, this way increasing consumer confidence, ensuring the quality and security of HPF. Application of this technology can overcome the problems of information security and ensure transparency when integrating with Internet of Things (IoT).

The analysis and systematization of FSC risks, associated with the COVID-19 pandemic and outlined above, shows that temperature modes control and its traceability through all stages are the key factors in the functioning of the CCC, which contribute to:

- reducing the risk of virus transmission (temperature plays an important role in time of SARS-CoV-2 survival on a surface of HPF);
- improving the safety of HPF (temperature dramatically affects the shelf life of the highly perishable food).

The Internet of Things (IoT) technology is the second most popular information technology today. IoT is used in FSC to monitor food production, processing and storage in real time mode, and it also allows setting up a set of smart production lines and storage lines to ensure the authenticity and reliability of the original data. IoT has proven to be efficient in the supply chains of HPF, ensuring food quality, consumers' health safety, and facilitating a faster reaction to various changes [38]. IoT technologies provide real solutions for monitoring the quality and tracking the food supply chains. Using IoT technology, the necessary data like temperature, humidity and other processing parameters, can be collected and integrated into the tracking system.

Conclusion

The COVID-19 pandemic has highlighted the importance of human health as a key factor in assessing the sustainability of the food supply chain and its major part — the CCC.

Improving the organizational structure of CCC for its proper management is an extremely urgent task, since its proper functioning ensures human health, ensures food safety and prevents the spread of SARS-CoV-2 through contaminated food products.

The COVID-19 pandemic has not only revealed vulnerability of FSC and CCC at certain points, but also determined that an important condition for their medium term and long term efficient functioning, especially under conditions of uncertainty, is their adaptability to external challenges.

The traditional logistics of the CCC features some problems, like actual absence of centralized system for data storage, low reliability of data, ease of forgery and difficulty in finding the responsible employees. These problems lead to the inability to guarantee consumers' rights for food safety, ensure the sustainable quality and security of HPF. To solve these problems, the tracking system of CCC logistics for agricultural products is proposed. This tracking system is based on the technologies of blockchain and Internet of Things (IoT).

It is necessary to adapt the benefits of these technologies in accordance with the current and developing national information systems for ensuring the quality and safety of food products, which will serve to reduce food losses in the country and improve the quality of people's lives.

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The authors declare no conflict of interest.