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# Blockchain-based traceability of the food supply chain: consumer perception and a case study

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## Abstract

Food safety and food frauds are crucial aspects in the growing and constantly changing food market. The first definition refers to hygiene and foodborne diseases prevention, the second refers to the security for a consumer to by a specific product and not a counterfeit. An improved traceability, based on blockchain systems, may help to prevent food safety and food security issues. Blockchain belongs to the distributed ledgers, a type of database in which each participant owns a copy of the same data and every change in a copy is automatically reflected on the other copies. It is designed to guarantee decentralization, transparency, immutability and traceability. As shown by a relevant number of projects that has been developed and applied, it suits to the food supply chain traceability.

An improved traceability based on blockchain can also be useful at the market level. For instance, Italian sounding is the practice to use Italian words, colours (such as the Italian flag colours) and names to give an Italian appearance to a product, irrespective of its country of origin and its production method, to promote it. It affects different sectors, but the food sector is the most damaged.

The present research is focused on the application of the blockchain to the traceability of the food supply chain, its impacts and its perception. Indeed, the application of these systems may have several advantages, but also negative impacts: the producers must accept to show transparency to the consumers, it may lead to a price increase (as the design and maintenance of a digital traceability systems have a considerable cost) and consumer profiling is an aspect that must be properly discussed.

To assess if the Italian consumers may be interested in the use of blockchain traceability for food, a survey has been performed on 500 users. The asked questions concern their interest and knowledge towards traceability, blockchain technology, shopping preferences, the suggestion of food categories (e.g. meat, fish and others) currently requiring an improved traceability. Lastly, the willingness to spend more to buy food provided with digital traceability was evaluated. The results revealed that respondents are generally interested in food traceability, they usually know what blockchain and digital traceability are, they buy food mainly at supermarkets, they are interested in knowing the origin of the food mainly for meat, fish and dairy, they would rather buy a product provided with digital traceability system instead of an unprovided competitor and they consider acceptable a 10-15% cost increase for a digitally traced product.

To complete the research, a concrete project/case study has been completely developed in collaboration with the innovative startup Franceschi srl, composed by Saporare and S|Trace. Saporare is an online shop of traditional Italian food and beverages (e.g. balsamic vinegar, honey, olive oil, wine) of small and medium sized producers and each product has a declaration of origin. The products will be traced with S|Trace, a blockchain-based traceability system provided with a web app for data upload, designed to ease the operation for the producers. Saporare acts as the third part in the supply chain, certifying the origin and the security of the products, but without substituting production disciplinaries or food control agencies: this makes the perfect use-case to study the application of the blockchain to the food supply chain.

Lastly, considering both costs and complexity of the blockchain, a pipeline facilitating the choice of the right technology has been developed. In particular, the developed pipeline may help to define which type of blockchain could be useful for each food supply chain and when a blockchain could be really effective.

# Abstract

Food safety e food security sono aspetti cruciali in un mercato globale in costante crescita e cambiamento. Il primo fa riferimento alla prevenzione di malattie di origine alimentare, il secondo indica la sicurezza per un consumatore di comprare un prodotto specifico e non uno contraffatto. Una tracciabilità migliorata, basata su sistemi blockchain, può aiutare a prevenire i problemi riguardanti la sicurezza alimentare. La blockchain è un database distribuito, cioè un sistema in cui ogni partecipante possiede una copia dello stesso database posseduta dagli altri dove ogni modifica in una copia viene automaticamente apportata alle altre. Garantisce decentralizzazione, trasparenza, immutabilità e tracciabilità. Come si evince dai numerosi progetti sviluppati e applicati, è un sistema perfetto per la tracciabilità della filiera alimentare.

Una migliore tracciabilità può essere utile anche a livello di mercato. Ad esempio, l'italian sounding è la pratica di utilizzare parole, colori (come la bandiera italiana) e nomi italiani, a prescindere dal paese di origine e del metodo di produzione, a scopo promozionale. Colpisce molti settori, ma quello più danneggiato è quello agroalimentare.

Questa ricerca è mirata allo studio delle applicazioni della blockchain alla tracciabilità della filiera agrifood, al suo impatto e alla sua percezione. L'uso di questi sistemi ha molti vantaggi, ma ha anche svantaggi: i produttori devono accettare di mostrare più trasparenza, il costo dei prodotti tracciati potrebbe aumentare (per via dei considerevoli costi di progettazione e manutenzione di questi sistemi) e la profilazione dei consumatori è un tema che va approfondito.

Per valutare l'interesse dei consumatori italiani verso l'utilizzo della tracciabilità digitale per il cibo, è stato svolto un sondaggio su 500 utenti. Le domande poste riguardano il loro interesse e la loro conoscenza verso la tracciabilità, la blockchain, preferenze di acquisto, suggerimenti su quali categorie di prodotti (carne, pesce, ecc.) necessitano una migliore tracciabilità. Infine, è stato valutato quale sia l'aumento di costo accettabile per prodotti dotati di tracciabilità digitale. I risultati mostrano che in media gli intervistati sono interessati alla tracciabilità del cibo, conoscono o hanno sentito nominare la blockchain, desiderano conoscere principalmente l'origine di carne, pesce e latticini, preferirebbero comprare un prodotto provvisto di tracciabilità digitale rispetto a un concorrente sprovvisto e l'aumento di costo accettabile per un prodotto tracciato con la blockchain è tra 10% e 15%.

Per completare la ricerca, è stato sviluppato un progetto in collaborazione con la startup innovativa Franceschi srl, che comprende Saporare e S|Trace. Saporare è un e-commerce di cibo e bevande della tradizionale italiana (aceto balsamico, miele, olio di oliva, vino), provenienti da piccoli e medi produttori, dove ogni prodotto ha una dichiarazione di origine. I prodotti venduti saranno tracciati con S|Trace, una piattaforma proprietaria di tracciabilità digitale basata sulla blockchain, provvista di una web-app per il caricamento dati, disegnata per essere facilmente fruibile. Saporare si pone come parte terza nella filiera, certificando l'origine e la sicurezza dei prodotti, senza sostituirsi a disciplinari di produzione o enti di controllo: è il caso studio perfetto per studiare l'applicazione della blockchain alla filiera agroalimentare.

Infine, considerando sia i costi che la complessità della blockchain, è stato sviluppato un diagramma di flusso per facilitare la scelta della giusta tecnologia da utilizzare. In particolare, questo diagramma può aiutare a definire quale tipo di blockchain è migliore per ciascuna filiera e quando la blockchain può avere maggiore efficacia.

# Introduction

## Food Safety

Food is a necessary and vital component of the life for the animals. Humans are no different even though sometimes we are prone to believe it. Food defines our history and culture as well as economy and politics of nations and supranational organizations (e.g., the European Union). In fact, we talk about food every day. However, our diet influences our health in many ways: malnutrition and undernutrition, obesity and other diseases are widely recognized to be dependent from diet and nutrition. Since 2016, globally more people are obese than underweight, and China and the USA alone have the highest number of obese people than any other country (NCD Risk Factor Collaboration, 2016). For what concerns Europe, the situation is alarming as more than half of the total adults are affected by obesity and other weight problems, which also lead to an alarming 70% of all deaths caused by weight-related pathologies and 70-80% of health care costs derive from the treatments for these pathologies (European Commission, 2020). Nevertheless, another important source of problems related with food are foodborne diseases. The World Health Organization (WHO) (2020a) defines these as “diseases caused by eating food contaminated with bacteria, viruses, parasites or chemical substances such as heavy metals”. These contaminations can occur in every stage of the food production, from the raw material to the post processed food and up to the storage phase. Contaminations can result from environmental contamination, soil, air and water pollution, as well as contamination during the food processing operations and storage. (WHO, 2020a).

The surveillance over these possible infections is based on the risk analysis, a framework designed to put in practice science-based decisions to avoid contaminations and outbreaks (Gkogka, 2019). It is composed by three different parts that work together and are interconnected in different ways: risk assessment, risk management and risk communication. These three parts work by following the precaution principle, “an option open to risk managers when decisions have to be made to protect health but scientific information concerning the risk is inconclusive or incomplete in some way”, according to the Regulation (EC) 178/2002, article 6 and 7 (EFSA, 2007).

Risk assessment is based on the analysis of the probability and the severity that a certain health problem, derived from the consumption of a contaminated food or beverage, have to affect the population. It consists in four main steps: the first step is to identify the potential hazard and which are its main sources, exposure assessment of this hazard in terms of potential intake, hazard characterization (the analysis of probability and severity of the adverse health effects that is cause) and risk characterization, which is the integration of the four previous steps (Gkogka, 2019).

Risk management is the selection and application of the measures suited to lower the risk of potential infections and outbreaks, which is consequent to risk assessment and it should always be based on the direction of the risk assessment (EC regulation 178/2002).

Risk communication is the last step and it is based on the interaction among the organs that compose the risk analysis framework system with food producers, the consumers and other interested parties to communicate the decisions and the potential risks (Gkogka, 2019).

In the European Union risk assessment is entrusted to EFSA, which base its decision on the analysis of external studies and laboratories, while the risk management is responsibility of the European Commission and the Member States that transform EFSA's direction in regulations (Chatzopoulou et al, 2020).

By estimating the number and the severity of foodborne illnesses, regulatory agencies, industry, consumer groups, and others can better target prevention measures and improve food safety (CDC, 2018).

Nevertheless, infections are always underestimated in number as the reported cases are only a part of the real case. To clarify it is easy to think about the "gastrointestinal viruses" or "stomach flu": these infamous illnesses are characterized by a variety of symptoms, like diarrhea, vomit, abdominal cramps and, in some cases, fever. The main source of infection are contact with an infected person or by ingesting contaminated food or water. These illnesses are caused by a group of viruses that replicate into the intestinal mucosa and this group include several different families, like caliciviruses, rotaviruses, adenoviruses, astroviruses, and coronaviruses (Bishop and Kirkwood, 2008). As the majority of these viruses give mild to serious similar symptoms, like vomiting and diarrhea, they generally are treated in the same way and rarely the pathogen is identified and reported. Fig 1 show the general problem in counting the total confirmed infection as only a part of the confirmed infections is successfully reported: the reported number is only the "tip of the iceberg" of a foodborne contamination or intoxication, as the effectively reported cases are the tip above the "sea level" of surveillance and many infections remain unreported (Devleesschauwer et al, 2015). For example, in the yearly statistics of the foodborne illnesses in the US, the biggest number of estimated number of illnesses is represented by unspecified agents (CDC, 2018) or globally the aetiological cause of near a half of the diarrhoeal cases and deaths is not known (WHO, 2017), meaning that the people that seek for care have been treated for a general foodborne contamination without analyze and confirm the pathogen or untreated at all.

This "burden-of-illness pyramid" is useful to understand how the esteems for foodborne illness cases are made, as a multiplier is calculated to fill the gap of under-reported cases (Pires and Devleesschauwer, 2021).

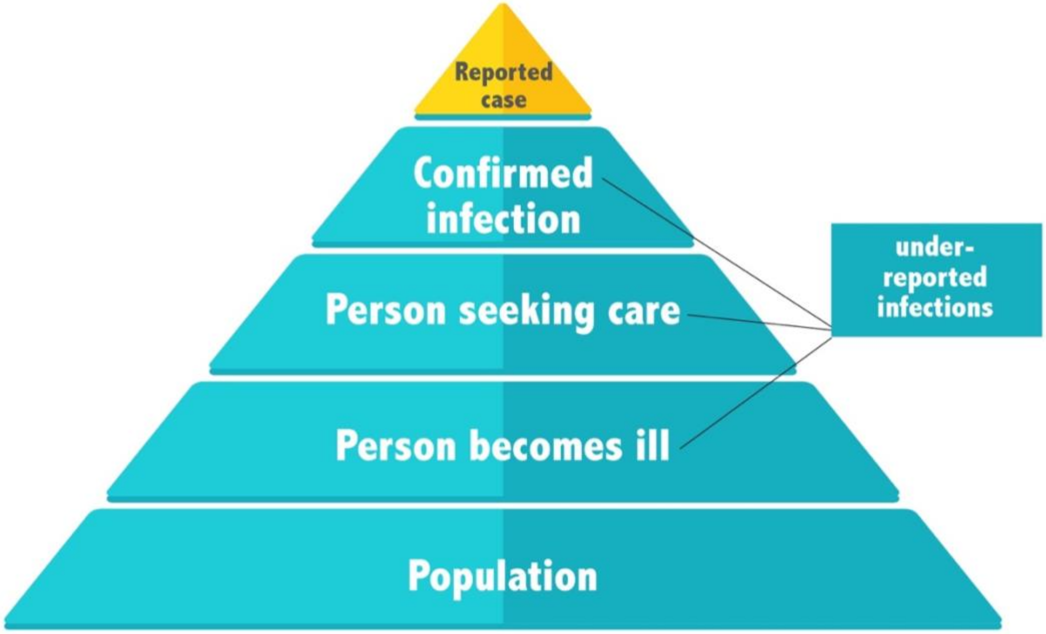


Fig 1. Infection pyramid adapted from Devleesschauwer et al (2015), Potter and Morris (2021) and WHO (2017). Foodborne disease infections are always underestimated in number, as only a small part of the population contracts an infection, then a part of the infected people becomes ill at the point of needing medical care and at this point only a correct diagnosis leads to the confirmation of a certain infection. Finally, only a part of the infections is reported. In this process a person may heal even if treated for a generic enteric infection or heal even if not treated, contributing to the under-reported infections.

There can be as much as 200 foodborne diseases (which is a disease contracted by ingesting food or beverages contaminated by a pathogenic organism or a chemical) and they range from diarrhea to cancers (WHO, 2020b). These infections can be caused from bacteria, viruses or parasites (Bintsis, 2017). However it is important to make a distinction between infection and intoxication: Potter and Morris (2021) stated that an infection occur when a live organism (such as bacteria, viruses or parasites) is ingested and the resultant disease comes from the establishment in the gastro-intestinal trait of human body of this pathogenic organism, whereas an intoxication is the ingestion of a toxin produced by an organism without having to ingest that organism (and this is the case of mycotoxin, for example) or a toxic chemical such as heavy metals or other pollutants. Regarding the number of infected people is impossible to find the exact data, but the WHO estimates that, all together, the 31 most important foodborne illnesses caused by bacteria, parasites, toxins and allergens cause about 600 million cases of foodborne diseases and a total of 420 thousands deaths each year and this number is underestimated. These 31 diseases cover for the 95% of all the reported cases, thus it is on these ones that studies and prevention are focused. The pathogens that cause diarrhoeal diseases accounted for the vast majority, with 550 million infections every year, and the two most common gastroenterical infectuos agents are norovirus (120 million cases) and *Campylobacter spp*. (96 million cases). Regarding Europe, WHO estimates 23 million cases of illness and 5 thousands deaths every year (WHO, 2017), making European citizens less and less trusting in the food system and supply chains (Flynn et al., 2019).

However, the situation become far more serious in the developing countries, where poverty and infrastructure scarcity lead to low hygienical standard and limited access to prevention and medical attention. For these reasons, diarrhea can be fatal especially in fragile individuals and in water scarcity conditions: it is well-known that Africa pays the highest price for food- and water-borne infections as each year more than 800’000 children die from the dehydration and debilitation consequent to diarrhea infections (Tambe et al., 2015).

### Bacteria

Bacteria are the most common infection agent related to foodborne diseases for number of reported infections, accounting for 350 million illnesses each year and close to 188 million deaths every year (WHO, 2015). Infections from bacteria usually generate gastrointestinal symptoms, such as diarrhea and vomit and frequently associated with abdominal pain and fever, that in some cases can be severely debilitating particularly due to dehydration.

In Europe, bacterial infection are the most abundant foodborne-related pathogens as shown from the most recent EU report on zoonoses (Fig 2), in which the main five pathogen are bacteria. The most common bacterial infections in Europe are in fact Campylobacteriosis, Salmonellosis and Shigatoxin-producing *Escherichia coli* (STEC-infections), followed by Yersiniosis and Listeriosis (EFSA, 2021). The situation has not changed in the last 10-15 years and the developing trend has not changed from 2015. Among these 5 bacteria, Campylobacteriosis, Salmonellosis, STEC-infections and Yersiniosis are generally associated with mild symptoms, but Listeriosis is characterized by a different trend as almost all the confirmed cases have been hospitalized (92% of the cases), making this last one the most severe foodborne illness in Europe.

A similar situation is found in the US, where Campylobacteriosis and Salmonellosis represent the two main pathogens among all the 31 infection agents. In total 48 million people contract foodborne infections, of which 128 thousand are hospitalized, and 3 thousand people die from foodborne diseases each year in the United States (CDC, 2018).

Campylobacteriosis has consistently been one of the most common foodborne illness in the EU and the US. In particular, 220 thousand cases have been confirmed in the EU, accounting for 59.7 infections for 100 thousand population in 2019 (EFSA, 2021). The genus genus *Campylobacter* is responsible for this pathology and the most common species are *C. jejuni* and *C. coli*. Usually characterized by diarrhea, nausea, abdominal pain and fever, but this bacterium has also been related with more serious consequences, such as other gastro-intestinal diseases and other system diseases like the Guillain–Barré syndrome, a nervous system pathology characterized by limbs paralysis. *Campylobacter* is not able to multiply outside a host, but it can survive in the environment thanks to biofilm production and other adaptions. This also allow *Campylobacter spp.* to pass from a host to another through food, mainly chicken (as *Campylobacter* is considered normal microflora of domestic birds), but also milk, cheese and water, but it can also be transmitted by contact with other animals (García-Sánchez et al, 2018).

The second most important foodborne disease in the world is Salmonellosis, caused by *Salmonella enterica* and other species. There are several subspecies and serovars, but it is mainly divided in typhoidal (causing typhoid fever, a disease characterized by abdominal pain, general weakness, constipation and headache that can last from weeks to months if not treated) and non-typhoidal, the second most important foodborne bacterium, which cause gastroenteritis and diarrhea, even though this serovars can cause a less severe form of enteric fever. Like *Campylobacter*, chicken meat and eggs are the main source of infection, followed by turkey, pig and cow meat, but it can also be found in vegetable products. Interestingly, *Salmonella* is now rarely found in eggs, but in 2016 it has been found in chicken feed: this makes feed an important source of infection for poultry, even if the most common human pathogenic serovars have not been found. *Salmonella* is also found in fresh and ready-to-eat vegetables that does not require any cook, thus this can be a potential source of infection that is particularly relevant as it can cause important outbreaks (De Cesare, 2018).

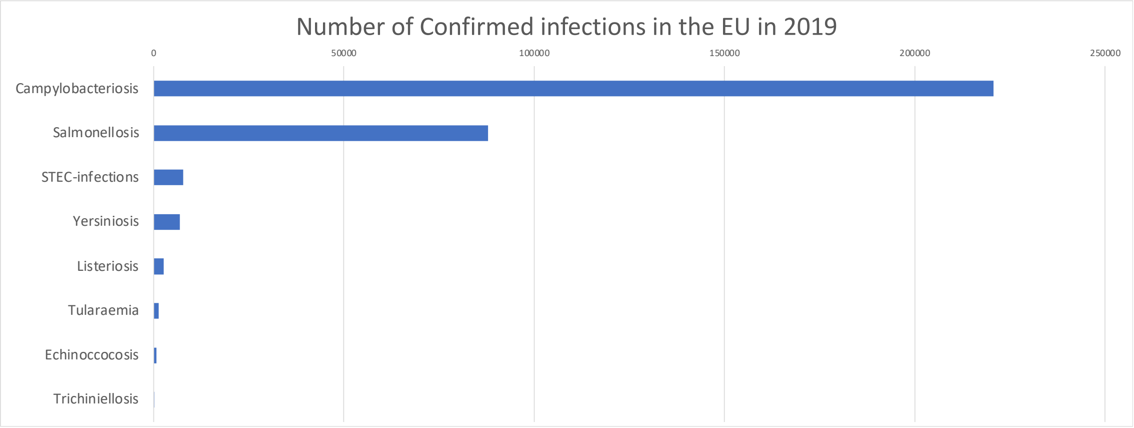


Fig 2. Number of reported infections of the main foodborne disease pathogens and parasites in the EU in 2019. Data retrieved from EFSA, (2021). Trichiniellosis total number is 39 confirmed cases. Data include the United Kingdom as until 31st January 2020 it remained a member of the EU.

### Viruses

Acute gastroenteritis is one of the most common health problems in the world, with an estimated 700 million infections every year (Bishop and Kirkwood, 2008). Foodborne viruses are widespread across the world and, altogether, they account for 125 million infections and 34 million deaths each year (WHO, 2015).

Among these infections, a relevant part come from foodborne-related viruses, a group that cause similar symptoms than intestinal bacteria: these symptoms are generally related with gastro-intestinal illness, diarrhea, vomit and in the most severe cases abdominal pain and fever. The most important difference is that bacterial infections can be treated with antibiotics, whereas viruses cannot and many infections cannot be prevented as well by improving the quality of food and water (Bishop and Kirkwood, 2008).

Calciviruses are widely recognized as the most important cause worldwide of viral gastroenteritis in human at all ages. Among all the enteric pathogens, as said beforehand, bacteria account for most of the cases, but *Norovirus* is the single pathogen responsible for the highest number of reported human infections (WHO, 2015).

Hepatitis A, however, is a virus that can be transmitted both by contact with an infected person or contaminated food or water. Most of the infections show no symptoms, but generally after 50 years old can cause nausea, vomit, diarrhea but also jaundice related to liver insufficiency and rarely the insufficiency leads to a necessary liver transplant. Globally 1.5 million infections are reported, meaning that the contamination may be significantly higher (Matheny and Kingery, 2012).

## Parasites

Parasites in food have been neglected for long as foodborne diseases agents, possibly due to their symptoms being chronical instead of acute, as well as their association with poverty and life condition with absence of sanitary infrastructure. However, in a changing world (due to climate change, globalization, population growth, etc) some of them are emerging or reemering as a problem (Robertson, 2018).

A familiar example may be Anisakiasis, caused by *Anisakis sp.*, a nematode that can parasitize the muscle tissue of many species of fish and can affect people after consumption of uncooked or unrefrigerated fish: sushi, a famous traditional raw fish meat and rice preparation, is one of the main infection source and Japan account for the majority of the infections. Anisakiasis was almost unknown in Europe and Italy in particular, before the popularity explosion of Japanese restaurants serving sushi as fish was previously eaten mainly cooked and the few infections that have been reported were through the ingestion of salted anchovies (as salt seasoning is not enough to kill this nematode). *Anisakis sp.* can penetrate the intestine mucosa and then cause gastrointestinal or allergy symptoms, causing a typical acute reaction with abdominal pain, vomiting and nausea or a chronical form with mild abdominal pain, weight loss and diarrhea (Bucci et al, 2013). To prevent infections, it is crucial to consume properly treated fish as cooking or blast-freezing can effectively kill this worm (Deardorff and Throm, 1988) and monitor the ready-to-eat through the supply chain to prevent potential outbreaks.

However, Echinococcosis is much more relevant in number of infections and in symptoms severity as it can lead to death even if after years. It is caused by the Cestode worm *Echinococcus sp.*: *E. granulosus* cause Cystic Echinococcosis and *E. multiocularis* cause

Alveolar Echinoccocosis. The eggs of these worms can be found in different body parts of sheep, pigs and other farmed animals and thus these eggs can be ingested by humans, even if the final hosts are dogs and foxes. When ingested, the larval forms (called Oncospheres) are released and they can penetrate the intestinal trait to infect mainly liver and lungs, but also other internal organs, where they slowly develop. It can take years to show relevant symptoms, mainly caused by organ compression and dysfunction (such as jaundice) and any infection can be completely cured by removing the parasite (Buttenschoen and Buttenschoen, 2003). The infection is rare in developed countries, but in Europe it is considered among the most important foodborne parasites (Bouwknegt et al, 2018) as Echinococcosis represent a serious illness, even though *Echinococcus sp.* are mainly found in foxes, sheep and cattle as these animals are part of its natural life cycle (EFSA, 2021).

Trichiniellosis is quite relevant as well and it is widely recognized as an important foodborne disease (EFSA, 2021). It is caused by *Trichiniella sp.*, a nematode that can cause a variety of symptoms depending on the growth stage in which the ingested individuals are, but they mainly cause typical gastrointestinal disease symptoms such as diarrhea, vomiting, nausea and abdominal pain, followed by a wide variety of secondary symptoms such as muscle pain, general weakness, headache and others. Similarly to *Echinococcus sp.*, the infection is through the ingestion of not sufficiently cooked mead of mainly domestic pork, for which the EFSA impose testing of samples, but also game animals, such as deer, wild boar, but also bear, crocodiles and marine mammals are among the potential source of infection. Globally, the number of confirmed infection has greatly decreased in the last decades, but control over domesticated and feral animal is important together with appropriate cooking (CDC, 2020; Robertson, 2018).

### Chemicals and Toxins

Contaminations with chemicals and toxins are lower in number compared to bacteria and viruses, accounting respectively for 218 thousand and 19 thousand deaths (WHO, 2015). An important difference from live pathogens is is that the toxicity of some chemical intoxication is not immediate, but require time and constant assumption to manifest. This is the case of cyanide intoxication in Cassava, a tuber rich in starch that is the carbohydrate source of many African, Asian and South American countries, that contains cyanogenic glucosides. If not properly processed before assuming it, a considerable amount of glucosides can be assumed and by time cause Konzo, a neurological disease. This is another example of under-reported disease as it is typical of poor countries with a lack in sanitary infrastructure (Kashala-Abotnes et al, 2018).

Mycotoxins are secondary metabolites produced by fungi. In function of the species, mycotoxins can cause acute toxic reaction (an example is the assumption of toxic mushroom mistaken for edible ones) and some of them are widely recognized as carcinogen agents, accounting for hundreds of thousand deaths every year: this is the case of toxin produced by microsocopic molds in particular from the genus *Aspergillum*, *Penicillum* and *Fusarium* which are common pathogens of cultivated crops. Aflatoxins are a group of around 20 different metabolites, produced by several species of *Aspergillum*, that are recognized as a potent carcinogen as well as capable of causing acute liver disorder in humans. Again, people in areas with less or no structured prevention and control regulations are the ones who risk the most, but mycotoxins are a problem worldwide (Wu et al, 2014). These toxins are mainly found in seeds like maize, peanuts and other are important agents in foodborne contamination, but their impact can be minimized if there is an improved control system. Dioxins are another toxic chemical that may be present in food, but differently from the other two previously described it is mainly generated as a byproduct of a wide variety of human activities (e.g. heavy industry, pesticides, sealants, paints and wood treatments). Among dioxins, polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and polychlorinated biphenyls (PCBs) are the most common and can be a serious problem for environment and human health. The main cause of dioxins assumption in human is through contaminated food, such as meat, fish or dairy because of the accumulation of dioxins in animal feed. The effects on human health are acute, such as alteration in liver and glucose metabolism, or chronic, causing immune and hormone system deficiency, alteration in fetal development and tumors and leukemia. Accurate controls on the supply chains of the main sources are essential in order to limit human consumption of dioxins and to remove any possible contaminated product batch as fast as possible, together with prevention measure such as the selection and cultivation method for animal feed (Weber et al, 2018). Concentrations of PCDD/Fs and PCBs have also been found in top predator birds, such as owls and kestrel, meaning that it can spread through the trophic levels (Zhang et al, 2021).

In conclusion, the 31 foodborne illness that the WHO consider relevant are certainly relevant, but there are some geographical differences (such as Konzo or Anisakiasis) that must be considered in order to build an appropriate strategy to contain infections ad outbreaks. Another important consideration is that for developed countries the situation can be far more serious as the lack in sanitary infrastructures and prevention represent a great threat to public health. At last, almost every food and preparation can be a source of infection: fish and seafood, chicken meat and eggs, meat and meat products, ice cream, raw milk, rice dishes, pasta and pasta salad, peanuts, flour, cold sandwiches, fruit juices and fresh produce can potentially be contaminated with any sort of pathogen, chemical and toxin. It is true that cooking may exponentially decrease the illness potential, fresh and ready-to-eat products have attracted great attention during the last 20 years, as there may be some weaknesses in their supply chain (Bintis, 2017).

## Bibliography

- Flynn, K., Villarreal, B. P., Barranco, A., Belc, N., Björnsdóttir, B., Fusco, V., Rainieri, S., Smaradóttir, S. E., Smeu, I., Teixeira, P., & Jörundsdóttir, H. Ó. (2019). An introduction to current food safety needs. In *Trends in Food Science and Technology* (Vol. 84, pp. 1–3). Elsevier Ltd.
- Athanassios, Chryssochoidis, & Scholderer, 2007; Jensen et al., 2019
- Bintsis, T. (2017). Foodborne pathogens. *AIMS Microbiology*, *3*(3), 529–563.
- Bishop, R. F., & Kirkwood, C. D. (2008). Enteric Viruses. *Encyclopedia of Virology*, *117*, 116–123.
- Bouwknegt, M., Devleesschauwer, B., Graham, H., Robertson, L. J., van der Giessen, J. W. B., Akkari, H., Banu, T., Koc, R. C., Chalmers, R., Cretu, C. M., Deksne, G., Djurkovic-Djakovic, O., Dorny, P., Dvoroznakova, E., Enemark, H. L., Gerard, C., Morales, M. A. G., Jurhar-Pavlova, M., Kapel, C., … de Waal, T. (2018). Prioritisation of food-borne parasites in Europe, 2016. *Eurosurveillance*, *23*(9).
- Bucci, C., Gallotta, S., Morra, I., Fortunato, A., Ciacci, C., & Iovino, P. (2013). Anisakis, just think about it in an emergency! *International Journal of Infectious Diseases*, *17*(11), e1071–e1072.
- Buttenschoen, K., & Buttenschoen, D. C. (2003). Echinococcus granulosus infection: The challenge of surgical treatment. In *Langenbeck's Archives of Surgery* (Vol. 388, Issue 4, pp. 218–230).

- CDC, (2018). Burden of Foodborne Illness: Findings. Available at https://www.cdc.gov/foodborneburden/2011-foodborne-estimates.html
- CDC, 2020. Parasites - Trichinellosis (also known as Trichinosis). Available at https://www.cdc.gov/parasites/trichinellosis/index.html
- Chatzopoulou, S., Eriksson, N. L., & Eriksson, D. (2020). Improving Risk Assessment in the European Food Safety Authority: Lessons From the European Medicines Agency. *Frontiers in Plant Science, 11*.
- de Cesare, A. (2018). Salmonella in Foods: A Reemerging Problem. In *Advances in Food and Nutrition Research* (Vol. 86, pp. 137–179). Academic Press Inc.
- Deardorff, T. R. and Throm, R. (1988). Commercial Blast-Freezing of Third-Stage Anisakis simplex Larvae Encapsulated in Salmon and Rockfish. In *Source: The Journal of Parasitology* (Vol. 74, Issue 4).
- Devleesschauwer, B., Haagsma, J. A., Angulo, F. J., Bellinger, D. C., Cole, D., Döpfer, D., Fazil, A., Fèvre, E. M., Gibb, H. J., Hald, T., Kirk, M. D., Lake, R. J., Maertens De Noordhout, C., Mathers, C. D., McDonald, S. A., Pires, S. M., Speybroeck, N., Thomas, M. K., Torgerson, P. R., … Praet, N. (2015). Methodological framework for World Health Organization estimates of the global burden of foodborne disease. *PLoS ONE*, *10*(12).
- EFSA. (2007). Opinion of the Scientific Panel on biological hazards (BIOHAZ) on microbiological criteria and targets based on risk analysis. In *EFSA Journal* (Vol. 5, Issue 3). Wiley-Blackwell Publishing Ltd.
- EFSA. (2021). The European Union One Health 2019 Zoonoses Report. *EFSA Journal*, *19*(2).

- European Commission, 2020. FOOD 2030 Pathways for Action. Healthy, Sustainable and Personalised Nutrition.
- EC regulation 178/2002. Available at https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32002R0178
- Flynn, K., Villarreal, B. P., Barranco, A., Belc, N., Björnsdóttir, B., Fusco, V., Rainieri, S., Smaradóttir, S. E., Smeu, I., Teixeira, P., & Jörundsdóttir, H. Ó. (2019). An introduction to current food safety needs. In *Trends in Food Science and Technology* (Vol. 84, pp. 1–3). Elsevier Ltd.
- García-Sánchez, L., Melero, B., & Rovira, J. (2018). Campylobacter in the Food Chain. In *Advances in Food and Nutrition Research* (Vol. 86, pp. 215–252). Academic Press Inc.
- Gkogka, E. (2019). *Food safety management strategies based on acceptable risk and risk acceptance*.
- Kashala-Abotnes E, Okitundu D, Mumba D, Boivin MJ, Tylleskär T, Tshala-Katumbay D. Konzo: a distinct neurological disease associated with food (cassava) cyanogenic poisoning. Brain Res Bull. 2019 Feb;145:87-91.
- Matheny, S. C., & Kingery, J. E. (2012). *Hepatitis A* (Vol. 86, Issue 11). www.aafp.org/afp
- NCD Risk Factor Collaboration. "Trends in adult body-mass index in 200 countries from 1975 to 2014: a pooled analysis of 1698 population-based measurement studies with 19· 2 million participants." The lancet 387.10026 (2016): 1377-1396.

- Pires, S. M., & Devleesschauwer, B. (2021). Estimates of global disease burden associated with foodborne pathogens. In *Foodborne Infections and Intoxications* (pp. 3-17). Academic Press.
- Potter, Morris. Foodborne infections and intoxications. Academic Press, 2021.
- REGULATION (EC) No 178/2002. Available at https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32002R0178
- Robertson, L. J. (2018). Parasites in Food: From a Neglected Position to an Emerging Issue. In *Advances in Food and Nutrition Research* (Vol. 86, pp. 71–113). Academic Press Inc.
- Pires, S. M. and Devleesschauwer, B. (2021). Foodborne infections and intoxications. Chapter 1. Academic Press, 2021.
- Tambe, A., Nzefa, L., & Nicoline, N. (2015). Childhood Diarrhea Determinants in Sub-Saharan Africa: A Cross Sectional Study of Tiko-Cameroon. *Challenges*, *6*(2), 229–243.
- Weber, R., Herold, C., Hollert, H., Kamphues, J., Blepp, M., & Ballschmiter, K. (2018). Reviewing the relevance of dioxin and PCB sources for food from animal origin and the need for their inventory, control and management. In *Environmental Sciences Europe* (Vol. 30, Issue 1). Springer Verlag.
- WHO, (2017). *THE BURDEN OF FOODBORNE DISEASES IN THE WHO EUROPEAN REGION*. Available at https://www.euro.who.int/__data/assets/pdf_file/0005/402989/50607-WHO-Food-Safety-publicationV4_Web.pdf

- WHO, 2020a. foodborne diseases. Available at https://www.who.int/health-topics/foodborne-diseases#tab=tab_1
- WHO, 2020b. Food Safety. Available at https://www.who.int/NEWS-ROOM/FACT-SHEETS/DETAIL/FOOD-SAFETY
- WHO (2015). Estimates of the global burden of foodborne diseases. ISBN: 978 92 4 156516. Available at https://apps.who.int/iris/bitstream/handle/10665/199350/9789241565165_eng.pdf
- Wu, F., Groopman, J. D., & Pestka, J. J. (2014). Public health impacts of foodborne mycotoxins. *Annual Review of Food Science and Technology*, *5*(1), 351–372.
- Zhang, Y., Zheng, X., Wang, P., Zhang, Q., & Zhang, Z. (2021). Occurrence and risks of PCDD/Fs and PCBs in three raptors from North China. *Ecotoxicology and Environmental Safety*, *223*.

## Food frauds

The practice of adulterating food is as old as the transition from nomadic to subsistence agriculture and it has been found through all the history of humanity (Kennedy, 2021). The FDA (Food and Drug Administration) defines food fraud as an “Economically Motivated Adulteration (EMA) that occurs when someone intentionally leaves out, takes out, or substitutes a valuable ingredient or part of a food. EMA also occurs when someone adds a substance to a food to make it appear better or of greater value” (FDA, 2021). A practical example may be the addition of cheaper vegetable oil to the more expensive olive oil and selling it as olive oil, basically making customer paying for a product that contains other cheaper ingredients. Such adulteration may also occur in products that are not food, such as animal feed, cosmetics, chemicals. Food fraud may affect 1% of the food industry, an apparently small part, but it can value from $10 to $40 Billion each year (FDA, 2021).

In contrast, the EU does not have a definition for food fraud but uses different definition in function of the context and this makes far more complicated the comprehension, the communication, and the ideation of strategies to prevent food frauds (Robson et al., 2021). EU laws are designed around food safety for the protection from foodborne diseases and intoxications, rather than against frauds to guarantee authenticity of the products (di Pinto et al., 2019).

The UK defines food frauds in two ways, which allow for a more complete understanding of the problem. The first definition is the deliberate misdescription of food, such as products substituted with other (e.g., farmed salmon sold as wild or basmati rice adulterated with cheaper varieties), a definition similar to the FDA’s EMA. The second definition add another element for the understanding of food fraud, which is the sale of unfit and potential harmful food, such as “recycling of animal by-products back into the food chain; packing and selling of beef and poultry with an unknown origin; knowingly selling goods which are past their ‘use by’ date” (Obbink et al., 2014).

A more comprehensive definition of food fraud may be “*the deliberate and intentional substitution, addition tampering or misrepresentation of food, food ingredients or food packaging, labelling, product information, or false or misleading statements made about a food product*” (Van der Meulen, 2015).

Food frauds may occur in several ways and concern several aspects of the food. Parameters such as country of origin, product type, detecting country, and types of adulterants are considered the most critical variables in the assessment of food fraud vulnerability (Rezazade et al., 2021).

Mislabelling, misbranding, counterfeiting, and document frauds are among the most common fraudulent practices (Visciano and Schirone, 2021), but most of them has no health effect on humans and it is only an economical problem, even if it may be quite relevant. However, there are fraudulent additions that can also have adverse effect. For example, olive oil, milk, saffron, orange juice, coffee and apple juice are among the most likely to be targeted for intentional and economically motivated adulteration by using several substances, such as low-quality vegetable oils, milk powder, starch, flour, but also sand, chalk powder and melamine (Choudhary et al., 2020).

Melamine, in particular, is a dangerous and illegal additive that has serious health effects and in 2008 in China it caused dozens of deaths and thousands of illnesses of various entity of liver and kidney disfunction. For this reason, several studies focused in the detection of this hazardous molecule by using chemical analysis (Liao et al., 2021).

An interesting case is the Sudan red dye, a textile colourant that has been fraudulently added to different products to improve their red colour. Although it has not a significant health effect, its use is forbidden, but it has been found in several red and orange food preparations, such as hibiscus, paprika, and saffron (Hu et al., 2017; Petrakis et al., 2017; Reile et al., 2020).

An important issue in those frauds is the detection, usually performed by using chemical analysis such as chromatography (like high performance liquid chromatography and gas chromatography), and spectroscopy (such as mass spectrometry), techniques that usually give relatively accurate results. However, the operations for the detection are sometimes difficult and need a considerable precision, which increases the complexity of detection also making these analyses not suitable for large-scale application. Nondestructive analysis techniques are interesting alternatives that allow to quickly obtain the relevant information of the sample without damaging its integrity. The most used non-destructive analysis techniques for food safety include optical techniques (such computer vision and spectral image techniques), electrical techniques (which include e-nose and e-tongue) and nuclear magnetic techniques (nuclear magnetic resonance and nuclear magnetic imaging technique) (He et al, 2020).

DNA analyses are another useful and important techniques used in food adulteration detection. These analyses allow, for example, to assess whether a food preparation contains ingredients derived from different species or variety from what has been declared on labels: a famous example is the horsemeat scandal, a food fraud consisted in the addition of horse meat to grounded bovine meat, that in 2013 caused a huge scandal and enlightened some of the weaknesses in the bovine meat supply chain in Europe (Robson et al., 2020). DNA barcoding is a technique that has been widely used in the last 20 years for the characterization of taxon in ecology that uses standardised DNA region to distinguish samples at all taxonomic levels (Valentini et al., 2009) that can be applied for the characterization of food ingredients to identify and prevent food frauds (Nehal et al., 2021). An interesting example is the fraudulent commercialization of shark meat sold as swordfish: swordfish fishery is one of the most important fishing activities that, if performed without the necessary attention, can result is the bycatch of other species, such as *Prionace glauca*, *Mustelus mustelus,* and *Oxynotus centrina*, all three threatened, vulnerable, and endangered shark species (Ferrito et al., 2019), making this a food fraud that threatens both consumers and the environment.

Mislabeling or hiding the origin of the ingredients is a fraud that allows the fraudulent placing on the market of products with a hidden story with the purpose of paying no taxes or products that does not fulfil the legal requirement, such as vegetables with illegal level of chemical residuals (Soon, 2020) or veterinary drugs (such as hormones or antibiotics) (Robson et al., 2020).

### Italian sounding

Some foods are intentionally mislabelled to give them an exotic appearance, to make them seemingly coming from a country instead of the country of origin (Obbink, 2014). Sometimes the product is declaredly produced in the real country of origin, but the appearance recalls the idea of another country. These practices have long been neglected despite their commercial importance and their considerable economic value (Carreño and Vergano, 2016). A peculiar and crucially important example of this fraudulent practice is the "Italian Sounding": it is the habit of giving names and/or colours that recalls the Italian ones, regardless of the country of origin and a fake "Made in Italy" appearance (Bonaiuto et al., 2021). To give to the products an Italian resemblance, the fraudulent producers can copy the real Italian name, either translating it (such as the American "parmesan" cheese) or simply by calling it with the real name, or the brand can be called with an invented name that recalls italian ones, such as "da Vinci" or "Gattuso" tomato sauce (Bonaiuto et al., 2021), or using colours such as the Italian flag on the packaging (Fig. 1 and 2). The use of fake italian product is so widespread that even the prime minister of Italy had been served with fake italian products (two wines and a cheese) when invited to the white house durin Barack Obama administration (Magagnoli, 2019).

Fig. 1. An example of Italian sounding in which a US produced cheese has been called "Mozzarella" even if it is declaredly produced in California. Photo taken by the author in 2016.

Fig. 2. An example of Italian names and colours used to recall the Italian origin of this "ricotta". Photo taken by the author in 2016.

Also, Italy has the highest number of Protected Designation of Origin (PDO), Protected Geographical Indication (PGI) and Traditional Speciality Guaranteed (TSG). These products, however, are frequently subject to frauds. The main motivation to commit frauds is illicit monetary gain and PDO, PGI and TSG products are meanly much more expensive that not protected equivalent products, thus are also more subjects to frauds (di Pinto et al., 2019). The motivation for food frauds may be the convenience of using lower cost ingredients, but also the seasonal variance of milk for cheese production, as some cheeses have been found containing milk from other countries. However, sometimes it can the result of errors and inaccurate management of the supply chain (di Pinto et al., 2015).

The EU has a protective set of law against the Italian Sounding that are designed to guarantee the authenticity of the products sold on the EU internal market, but this cannot be said for foreign markets. The issue not only affects Italian producers and the entire European agrifood sector, but also the credibility and trust in the products sold on the internal market in general (Carreño and Vergano, 2016).

Italian sounding fraud can also affect wine. A fraud concerning different Italian wines was discovered in 2014 by the finance guard of Siena (Tuscany): more than 160000 L of poor-quality wine and 2350 State marks were meant to be sold as expensive and higher quality wines, such as the famous Brunello and Rosso di Montalcino (Bartolini et al., 2018). The Italian Sounding and fake Made in Italy value is more than €100 Billions, an astonishing amount of money that also influence the export value of Italy. The most counterfeited products are cheese, cured meat, preserves (e.g. tomato sauce), pasta, and wine, which resulted as the single most counterfeited product in 2019 (Costa, 2020; ICQRF, 2021).

Improved traceability is one of the most effective way to solve this problem, as well as specific marketing strategies that can "educate" the foreign consumers, as they pay little attention to the labels when they buy food (Francioni and Albanesi, 2017), associated with analytic controls that can confirm the real origin of the Italian products (Visciano and Schirone, 2021).

## Conclusions

Food fraud can derive from different elements. The most common is the deliberate addition of similar substances to a food product to dilute it and to maximise the profitability of the sold food. Another common practice is to deliberately mislabel the product to sell it for something more expensive, which is similar to the previous practice, or to copy the texture of the food to sell it under a different name which recalls the "italianity" of the product (Italian Sounding). A product may be sold with a counterfeited declaration of origin or without the necessary declaration of origin and supply chain control. Lastly, a product may be recycled back in the supply chain, sometimes added with preservatives and/or colourants to make it more fresh-looking and appealing, also called relabeling (Birse, 2021; Todd et al., 2022).

Furthermore, there is a considerable lacking in clear guidance for the food industry for the prevention and the mitigation of food frauds. Several official documents are available to help guide the food industry; the main problem, however, is that these documents are nonspecific to supply chains, which has left a substantial gap in knowledge that working on the supply chains is necessary to protect the food supply and to effectively reduce EMAs and food adulteration (Robson et al., 2021).

The opposite of food fraud is food authenticity, which occurs when the quality and characteristics match exactly what is claimed on the labels. In short, when “food is what says it is”, and it is rather a state than an act (which, on the opposite, is food fraud). Food authenticity is not an intentional or unintentional act, but it is affected both by intentional and unintentional acts (Robson et al., 2021). This state is what must be protected and what consumers ask, as they are gradually losing trust in the food systems and they ask new question rather than if a food is convenient, tasty, and filling (Steier and Friedlander, 2021), thus effective ways to track the authenticity of food must be found and implemented at supply chain level (Manning and Soon, 2016).

## Bibliography

- Bartolini, F., Brunori, G., Grando, S., Minarelli, F., Prosperi, P., Raggi, M., et al. (2018). National report: Italy. H2020-SFS-2014-2 SUFISA grant agreement 635577.
- Birse, N. (2021). Exploring recent innovations in ambient mass spectrometry to deliver a paradigm shift in food safety, security and authenticity (Doctoral dissertation, Queen's University Belfast).
- Bonaiuto, F., de Dominicis, S., Ganucci Cancellieri, U., Crano, W. D., Ma, J., & Bonaiuto, M. (2021). Italian Food? Sounds Good! Made in Italy and Italian Sounding Effects on Food Products' Assessment by Consumers. Frontiers in Psychology, 12.
- Carreño, I., & Vergano, P. R. (2016). Food: Geographical indications, "food fraud" and the fight against "italian sounding" products. European Journal of Risk Regulation, 7(2), 416–420.
- Choudhary, A., Gupta, N., Hameed, F., & Choton, S. (2020). An overview of food adulteration: Concept, sources, impact, challenges and detection. International Journal of Chemical Studies, 8(1), 2564–2573.
- Costa, C. (2020). Italian Sounding food: che cos'è e perché è così importante. Agrifood.tech. Available at https://www.agrifood.tech/sicurezza-alimentare/italian-sounding-food-che-cose-e-come-funziona/
- di Pinto, A., Bottaro, M., Bonerba, E., Bozzo, G., Ceci, E., Marchetti, P., Mottola, A., & Tantillo, G. (2015). Occurrence of mislabeling in meat products using DNA-based assay. Journal of Food Science and Technology, 52(4), 2479–2484.

- di Pinto, A., Mottola, A., Marchetti, P., Savarino, A., & Tantillo, G. (2019). Fraudulent species substitution in e-commerce of protected denomination origin (pdo) products. Journal of Food Composition and Analysis, 79, 143–147.
- FDA (2021). Economically Motivated Adulteration (Food Fraud). Available at https://www.fda.gov/food/compliance-enforcement-food/economically-motivated-adulteration-food-fraud
- Ferrito, V., Raffa, A., Rossitto, L., Federico, C., Saccone, S., & Pappalardo, A. M. (2019). Swordfish or shark slice? A rapid response by CoiBar–RFLP. Foods, 8(11).
- Francioni, B., & Albanesi, G. (2017). THE ITALIAN SOUNDING PHENOMENON: THE CASE OF GERMANY. International Journal of Economic Behavior, vol 7, pp 39–50
- He, Y., Bai, X., Xiao, Q., Liu, F., Zhou, L., & Zhang, C. (2021). Detection of adulteration in food based on nondestructive analysis techniques: a review. In Critical Reviews in Food Science and Nutrition (Vol. 61, Issue 14, pp. 2351–2371). Taylor and Francis Ltd.
- Heinemann, S. (2019). Italian Sounding. The Economy in Names, 3, 59. Proceedings of Names in the Economy 6. International Conference, Uppsala, 3–5 June 2019
- Hu, Y., Wang, S., Wang, S., & Lu, X. (2017). Application of nuclear magnetic resonance spectroscopy in food adulteration determination: The example of Sudan dye i in paprika powder. Scientific Reports, 7(1).
- ICQRF. (2021). Report attività 2020. Available at https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/394

- Kennedy, S. P. (2021). History of food fraud and development of mitigation requirements and standards. In Food Fraud (pp. 9-22). Academic Press.
- Liao, X., Chen, C., Shi, P., & Yue, L. (2021). Determination of melamine in milk based on β-cyclodextrin modified carbon nanoparticles via host–guest recognition. Food Chemistry, 338.
- Magagnoli, S. (2019). The Italian Way of Eating Round the World: Italian-sounding, Counterfeit, and Original Products Magagnoli, S. (2019). The Italian Way of Eating Round the World: Italian-sounding, Counterfeit, and Original Products. Senri ethnological studies, 100, 173-195.
- Manning, L., & Soon, J. M. (2016). Food Safety, Food Fraud, and Food Defense: A Fast Evolving Literature. Journal of Food Science, 81(4).
- Nehal, N., Choudhary, B., Nagpure, A., & Gupta, R. K. (2021). DNA barcoding: a modern age tool for detection of adulteration in food. In Critical Reviews in Biotechnology (Vol. 41, Issue 5, pp. 767–791). Taylor and Francis Ltd.
- Obbink, N., Frissen, J. M., & Post, S. B. (2014). OFFICIAL CONTROL: J. Food Frauds. Meat Inspection and Control in the Slaughterhouse (Pages: 628-638)
- Petrakis, E. A., Cagliani, L. R., Tarantilis, P. A., Polissiou, M. G., & Consonni, R. (2017). Sudan dyes in adulterated saffron (Crocus sativus L.): Identification and quantification by 1H NMR. Food Chemistry, 217, 418–424.
- Reile, C. G., Rodríguez, M. S., Fernandes, D. D. de S., Gomes, A. de A., Diniz, P. H. G. D., & di Anibal, C. V. (2020). Qualitative and quantitative analysis based on digital

images to determine the adulteration of ketchup samples with Sudan I dye. Food Chemistry, 328.

- Rezazade, F., Summers, J., & Lai Teik, D. O. (2022). A holistic approach to food fraud vulnerability assessment. Food Control, 131.
- Robson, K., Dean, M., Brooks, S., Haughey, S., & Elliott, C. (2020). A 20-year analysis of reported food fraud in the global beef supply chain. Food Control, 116.
- Robson, K., Dean, M., Haughey, S., & Elliott, C. (2021). A comprehensive review of food fraud terminologies and food fraud mitigation guides. In Food Control (Vol. 120). Elsevier Ltd.
- Soon, J. M. (2020). Application of bayesian network modelling to predict food fraud products from China. Food Control, 114.
- Steier, G., & Friedlander, A. (Eds.). (2021). Food System Transparency: Law, Science and Policy of Food and Agriculture. CRC Press.
- Todd, M., Guetterman, T., Sigge, G., & Joubert, E. (2021). Multi-stakeholder perspectives on food labeling and health claims: Qualitative insights from South Africa. Appetite, 167.
- Valentini, A., Pompanon, F., & Taberlet, P. (2009). DNA barcoding for ecologists. In Trends in Ecology and Evolution (Vol. 24, Issue 2, pp. 110–117).
- Van der Meulen, B. (2015). Is current EU food safety law geared up for fighting food fraud?. Journal für Verbraucherschutz und Lebensmittelsicherheit, 10(1), 19-23.

- Visciano, P., & Schirone, M. (2021). Food frauds: Global incidents and misleading situations. In Trends in Food Science and Technology (Vol. 114, pp. 424–442). Elsevier Ltd.

## Blockchain on supply chain

### Blockchain Technology

The consumers' awareness about the relevance of food safety for their health has been greatly increased in recent times (Losasso et al., 2012), and, at the same time, their trust in the origin and quality of food diminished, so that they recurrently asked for reliable certifications and traceability systems (Zhang, et al., 2020).

Improved traceability may be a conceptually simple, but practically more complex solution for the problems deriving from food safety and food frauds. There are different ways to achieve a reliable and useful improved traceability system and the most mentioned is by using digital traceability systems. Blockchain (BC) and Blockchain technologies (BCTs) are among the most recent technological tools introduced in the software panorama and they may represent a possible answer to the consumers' needs. BC belongs to the Distributed Ledger Technologies (DLTs), a common shared database among all the participants. BCs or DLTs are both systems that enhance trust in situations where a group of nodes (the physical devices in which the data copies are stored) or parties that take part in the system do not fully trust each other (Cachin and Vukolic, 2017). BC and DLT are different compared to centralized systems, where data are stored in a single place (e.g. a server) and only a single subject has the control on this data. Each participant in the distributed ledger owns an identical copy of the ledger and any change applied is reflected in every single copy owned by the participants. In a blockchain, every transaction between two participants is recorded permanently and these records take the name of "blocks", while each computer or other device that is used for blockchain processing is called "node".

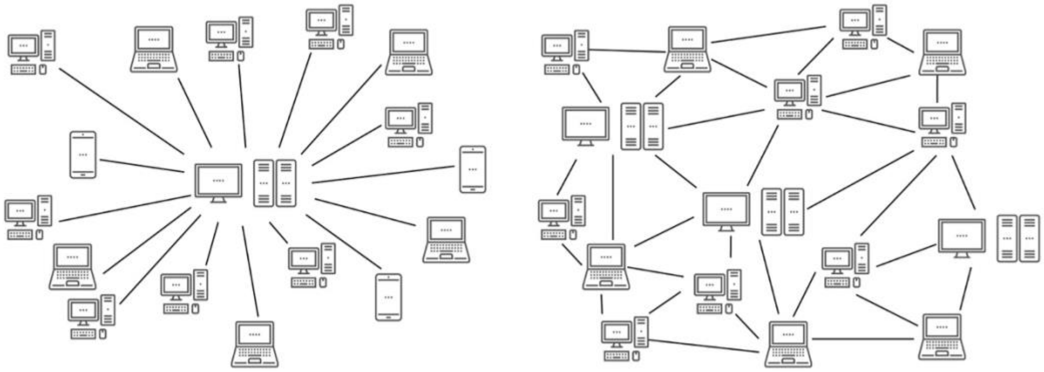


Fig. 1. Scheme of a central database on the left, where each device connects to a central server to access to the information; scheme of a distributed database on the right, in which all the participants (also called "node") share the same copy of a data record and every change is reflected on the copy owned by the others.

The shared data are encrypted: encrypting data ensures a high level of security, which is the first important benefit of this system. A change on a block must be accepted by all the other participants and it is impossible to apply any change without public consensus (which is the 51% of the participants in a BC system), thus data are even more protected. These are the four main characteristics of a blockchain: decentralization (as the data a shared), safety (it is tamper-proof), immutability (thanks to the consensus mechanism) and transparency.

Nevertheless, these features are relative to the diffused blockchain, like the *permissionless* BC used for Bitcoin (Nakamoto, 2008). In this system every block is immutable, it could be changed only if there is consensus by all the other participants and this guarantees to every subject to access to all the previous transactions, an essential element in a system where there is a lack of trust among the subjects and the system itself is the only trustable source.

Furthermore, it adds a timestamp to ensure that data existed in a specific moment, which is important for preventing double spending. Timestamp also allows the system to recognize the longest chain linked to a Bitcoin and it automatically erase the shorter ones while overwriting the longest chain data, to update constantly the shared ledger and to prevent the creation of a copy of a Bitcoin, but is also useful in other applicative fields, such as supply chain traceability (Crosby et al., 2016).

In order to add a transaction, “mining” must be performed: mining is a process that adds transaction records to the blockchain, achievable through solving computing problems that are very difficult to perform and are highly energy expensive (Vranken, 2017) and its energy cost has a considerable impact on the environment (Inacio, 2021). This type of system allows anyone to be part of the chain by solving computational problems and it is called “Proof of Work” (PoW): like mining, it is energy expensive and requires a highly computational power, while ensuring safety to the detriment of speed (in terms of transaction per second) and accessibility (Vukolic, 2015). There are other cryptocurrencies based on similar or slightly different systems, but all of them have in common to be *permissionless* like Bitcoin: a *permissionless* BC is characterized by having no limited access to the information enclosed in the public ledger and every subject can be a miner (Stifter et al., 2021).

There are two other types of BCT: *permissioned* and *private* BC. In these two different systems the decentralization and the safety protocols that are typical of the *permissionless* BC are sacrificed in order to ease operations, allowing also for a faster system, and to reduce the costs (Vukolic, 2015).

*Permissioned* BC means that data are public but only some selected subject can write the data (or those subjects can add blocks) and the data can still be shown to the public: this type is particularly suitable for product certification, due to the possibility for the companies involved in the production and logistic to share the data with the public, in particular with the customers. This BCT also allows to store data that can be hid to the public, but it can be useful as document storage (e.g., selling price) or for disciplinary requirements (e.g., analytic analysis) (Vukolic, 2015).

*Private* BC is very similar to the *permissioned* BC, except that data are no longer available to the public, but they remain shared only with the subject involved in these systems: *private* BC is suitable for finance transactions among subjects that do trust each other (e.g., banking transactions) (Vukolic, 2015; Cachin and Vukolic, 2017).

These BCTs can provide a cryptographically secure and immutable record of transactions and associated metadata, such as origin of the materials, process steps, documents and others, all linked across the whole supply chains and, for these reasons, the BCTs are frequently reported as possible solutions in different areas (Pearson et al., 2019) and they became increasingly popular in the last decades, as assessed by the high number of scientific articles concerning (BC) available in both Scopus and Web of Science (Fig 2).

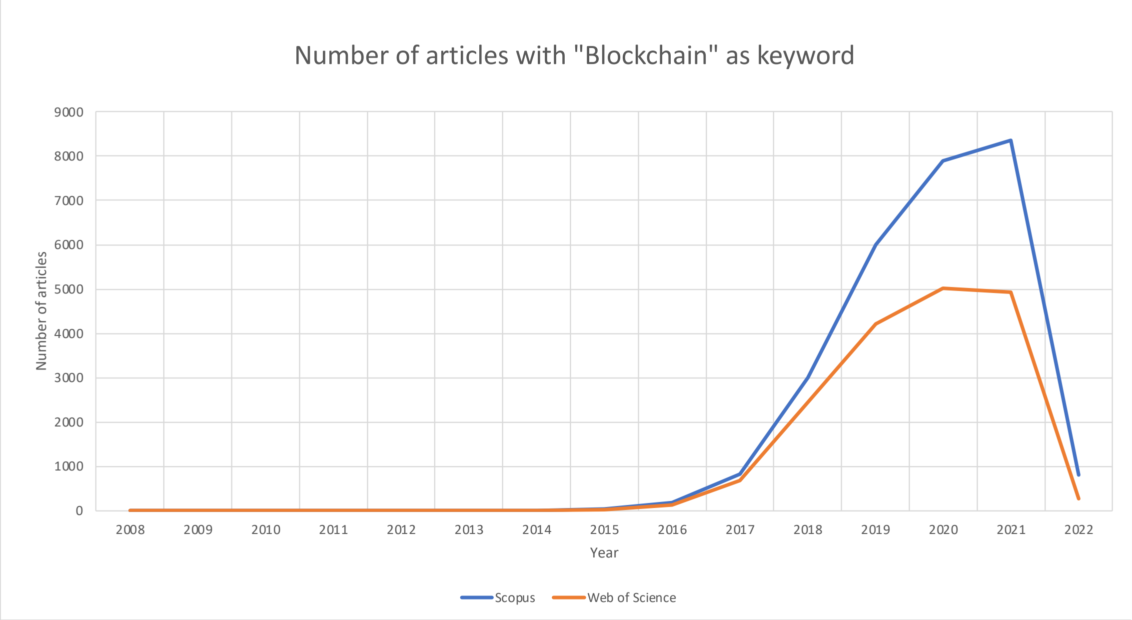


Fig. 2. Number of articles with "Blockchain" as keyword on Scopus and Web of Science. The search has been set from 2008 as it was the year in which Satoshi Nakamoto (2008) published the Bitcoin Whitepaper.

In Scopus, only 1 scientific article is related to BC before 2013, whereas their number rapidly rises to more than 3,000 in 2018, it doubles to 6,000 in 2019 and then up to 8,360 in 2021. Most of the publications up to 2015 were related to system architecture, cryptography, Bitcoin, and cryptocurrencies.

Interestingly, Noizat (2015) described the first attempt to apply BCTs to a new field (electronic vote) and since then, several articles explored the use of BCTs as tools for traceability, also applied to agrifood supply chains (Fig 3 and 4). The popularity trend of the BCTs application followed the same trend as the BC one: by searching "Blockchain supply chain" on Scopus, 45 articles are found in 2017, but in 2018 the number quadrupled to 180, peaking in 2021 with 943 papers. Same goes for the keywords "blockchain food", as only 9 articles are found in 2017 and it rises to 50 and 121 in the next two years and tops a 233 in 2021. Even if the growth is now not as rapid as in 2016-2019, it still grows year after year as the applications of the BCT to the supply chains are still growing in popularity (Powell et al., 2022).

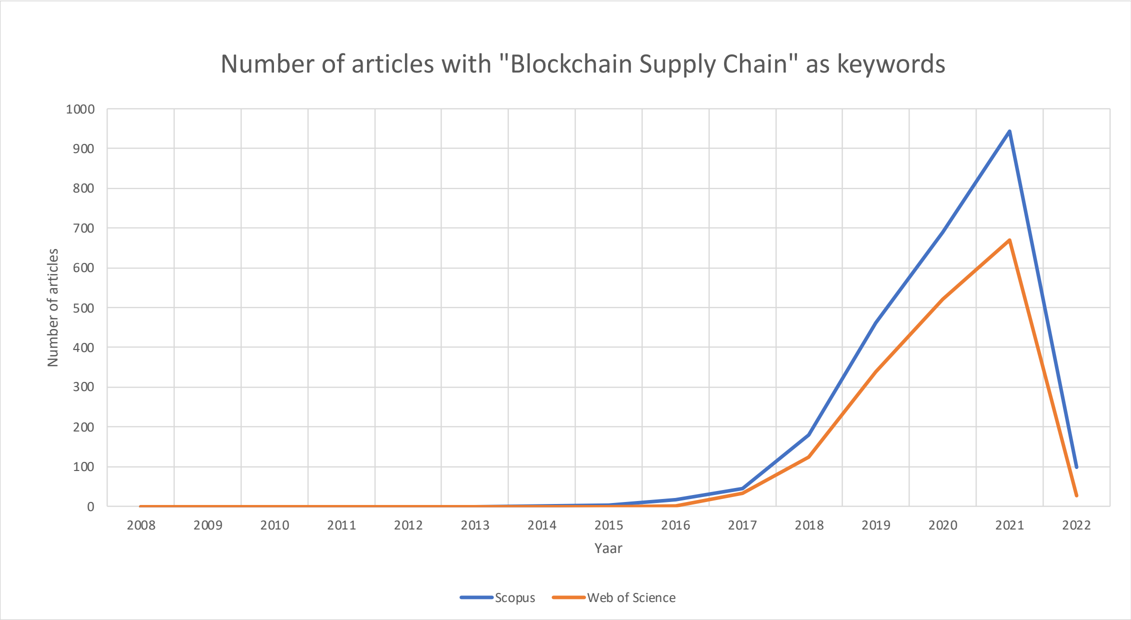


Fig. 3. Number of articles with “Blockchain Supply Chain” as keywords on Scopus and Web of Science. The search has been set from 2008 as it was the year in which Satoshi Nakamoto (2008) published the Bitcoin Whitepaper.

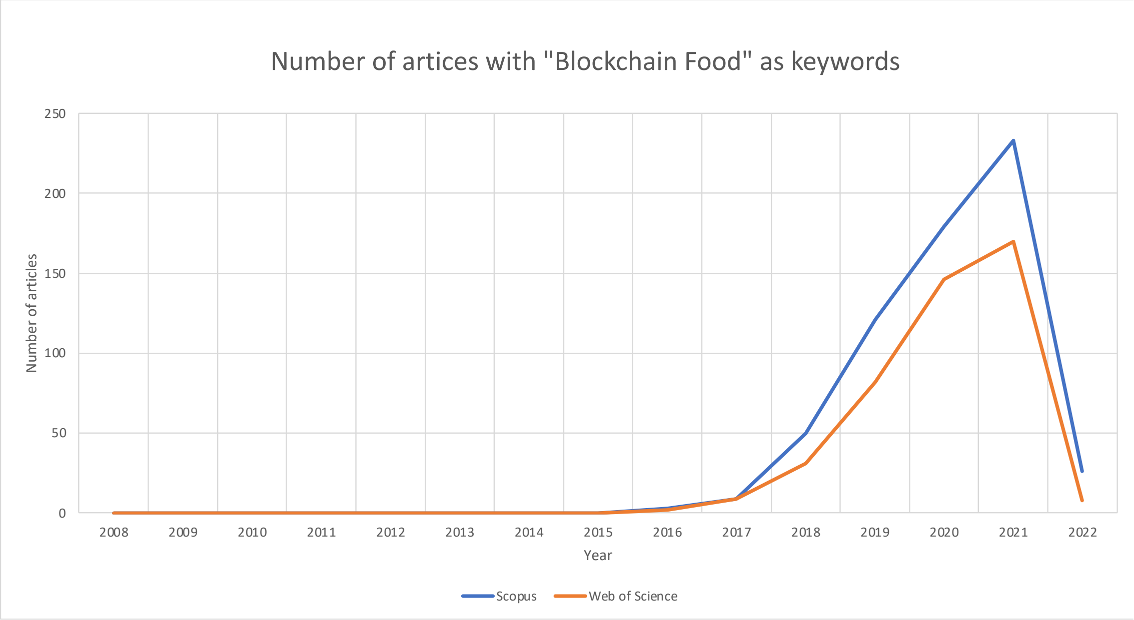


Fig. 4. Number of articles with “Blockchain Food” as keywords on Scopus and Web of Science. The search has been set from 2008 as it was the year in which Satoshi Nakamoto (2008) published the Bitcoin Whitepaper.

## Food traceability

Traceability has several definitions, in function of the environment that is considered. It can be defined by international standards, by Codex Alimentarius, by international laws, and by scientific literature. However, all of these contexts have a different focus, and they are more specific towards their fields, while lacking in the others (Olsen and Borit, 2013). If traceability is defined as the origin of all the raw ingredients, it lacks in the information about the processes that, sometimes, are vital for food preparations. This leads to an extended definition of traceability, that is “The ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications” (Olsen and Borit, 2013). This definition is complete and include the needs to record the information: for these reasons it suits much better in the context of digital traceability, as by using BCTs or other DLTs the advantage is to greatly ease the operation of recording.

This definition also includes the additional data that BCT consent to deliver to the consumers, such as cultivar (in case of plant-based product) or race (in case of animal-based product), feeding, eventual agricultural protocol (organic or integrated management), etc. These data assume a relevant importance in traditional food products supply chain, particularly in PDO (Protected Designation of Origin) products. Traditional food products, for example PDO products in Italy, are protected by Codes of Practice and they must be produced following these regulations, suited to follow the traditional local food-making process (Scuderi and Timpanaro, 2019).

The object of traceability is defined as Traceable Resource Unit (TRU) (Myo MinAung & Yoon SeokChang, 2014) and in the agrifood context, each supply chain has its own TRU, as it depends on the structure of the supply chain itself (Badia-Melis et al., 2015). In case of ham supply chain, the TRU is the pork leg and it can be traced from the farm to the market shelf, same as beef, lamb or chicken meat. The exception is represented by minced meat, which is composed by different part of, in many cases, different animals, thus the TRU would be a batch of that minced meat. A similar case in a different agricultural field is wine supply chain, especially in case of a cooperative winery, in which each bottle of wine contains grape coming from different producers. Generally, in every supply chain that includes a mix of different animals or plants, the TRU should be the product after the mixing of the raw material, especially in case of a digitally traced supply chain.

## Blockchain in food traceability

The application of the blockchain to the food supply chain has been described in a considerable number of papers. Interestingly, however, several proofs of concept and other projects related to the application of the BC to the supply chains and the agrifood supply chain in particular have been described more in newspaper journals than in scientific publications. This choice, probably due to marketing strategies and patent protections, does not allow a full understanding of the output of these projects, whereas their analysis and discussion in scientific journals may lead to relevant improvements and a better and deeper understanding of the true applicative value of the BCTs to the agrifood supply chains.

The first application that has been described is the Walmart-Hyperledger partnership, that was initially focused on the traceability of mango and pork meat, which enabled to instantly access to data that, in the traditional way, with paper documents and offline traceability, would need days or weeks (Hackius and Petersen, 2017; Zhao et al., 2016). After this first pilot project, Walmart extended the blockchain tracebility to 25 total supply chains from 5 different producers (https://www.hyperledger.org/learn/publications/walmart-case-study). Hyperledger is a public framework, supported by a confederation of big companies, and it includes two main projects: Hyperledger Fabric (https://www.hyperledger.org/use/fabric ), which is based on a modular approach, where multiple different consensus can be plugged based on the requirement, and the most basic one used is the Byzantine Fault Tolerance(BFT), a system ensuring consensus despite the participation of malicious user in the chain that could try to falsify data (Vukolic, 2015). This system is faster (it allows more transaction per second) and the blocks are lighter in comparison to traditional PoW systems.

Nevertheless, in order to work, all the nodes must be known, thus this BFT-based proto-col is best fit for permissioned BCs, which are the most suitable BC-based technologies for agrifood supply chains. Hyperledger Sawtooth (https://sawtooth.hyperledger.org/), which is the solution for a semi-permissioned, public approach and it is based on a modular system that does not use a Certification Authority like Fabric, but an elliptic curve encryption key that allows the permissionless approach. It is based on Proof of Elapsed Time (PoET), a mechanism based on the ability to change the consensus mechanism in which the validators are chosen by requesting a randomized wait time from the enclave and the validator with the shortest time claims the role of the leader and can add blocks to the blockchain. Thanks to this architecture, it is capable of saving much more energy that the other consensus mechanisms (Olson et al., 2018).

IBM has its own Food Trust, a permissioned highly flexible and scalable blockchain designed for supply chain traceability. Among the partners, there is an important Belgian coffee producer named Beyers Koffie that distributes coffee for labels like Kimbo, a famous Italian brand. IBM, Beyers Koffie and other companies, designed an app for coffee traceability named "Thank my Farmer", that allows the traceability of coffee from farm to cup and connects farmers, roasters, importers and all the actors in the supply chain, to match the needs of young consumers that ask for more transparency and sustainability (https://www.ibm.com/blockchain/resources/food-trust/agriculture-commodities/).

Ethereum is a smart contract based blockchain platform that is particularly interesting due to the smart contracts themselves. "Smart contracts are decentrally anchored scripts on blockchains or similar infrastructures that allow the transparent execution of predefined processes" (Ante, 2021), a mechanism that allow for intelligent and useful automation in the supply chain management. Regarding application on this platform, the use case section of this study provides for a complete and deep analysis of the case-study Saporare-S|Trace (https://saporare.com/it/), in collaboration with the innovative start-up Franceschi srl.

Two interesting case studies are provided by the Italian blockchain provider EZLab, which are Cantina Volpone (https://placidovolpone.it/blockchain-vini/), that is the first world blockchain on wine, and Olio Nece (https://www.olionece.it/blockchain-traceability), both single-owner blockchain that on one hand do not represent a good example of proper blockchain traceability, but on the other hand are a really good example for the assessment of the digital traceability of the traditional Italian products traced with the blockchain.

One of the most useful and complete is the egg supply chain traceability described by Bumblauskas et al. (2020), the case of Bytable's Trace my Eggs. This study is focused on the implementation of Hyperledger Sawthoot for the egg traceability of a Midwest U.S.A. egg producer. This proof of concept is particularily relevant as the system architecture and its working mechanisms are well and deeply described. It represents a unique case, as most of the scientific papers are focused on different aspects, such as challenges for the blockchain adoption in the whole agrifood supply chain instead of describing in such a detailed manner a proof of concept.

### User profiling on Blockchain systems

User profiling is a neglected subject, particularly regarding blockchain. On scientific databases such as Scopus or Web of Science, the number of pertinent articles is surprisingly low, even if blockchain providers such as IBM offer services of user profiling.

User profiling is the activity of gathering and identifying the data about a user interest domain and using them to understand more about this user. This data can be used to provide satisfaction to that user, in the form of personally tailored advertisement or suggestion for contents. User profiling can be done explicitly by asking the users to compile form and entering data such as age and email, implicitly by using systems that are designed to learn more about the user or in a hybrid way that combine the previous two (Kanoje et al., 2014). In the Internet of Thing ecosystem and in the online environment the personal devices generate a considerable amount of data that can become particularly valuable due to user profiling. Users are bound to face considerable difficulties in understanding the size and the meaning of these collected data. Organizations gain personal information about entities from a variety of different sources, such as location, internet searches, buying behaviors, lifestyle, and activities (Demertzis et al., 2020). However, in the EU there is a regulation called General Data Protection Regulation (GDPR) that require the users to be able to control their personal data, consent to the use of these data and be informed over the use that these data are required for (Rantos et al., 2018)

The GDPR is a wide and articulated legislation that include 99 articles, but the main objective is "the protection of personal data of natural persons and their processing of their personal data" (Cornock, 2018). Blockchain user profiling makes no difference, and it is included in the GDPR, which also imposes to the various companies to ask for the use of personal data or cookie installation and also regulates the implicit user profiling systems.

However, there is a serious gap in implementation or applications that can help the user to obtain information about the use of their personal data and how to protect them and how to deal with personal data leakage incidents (Wachter, 2018).

Blockchain Technology should make no difference and it should be considered under the direct protection of the GDPR (Rantos et al., 2018; Demertzis et al., 2020), thus the user that access to the systems should be informed about the data that those system would use and the use that the company would do of the personal data. Furthermore, Blockchain has been considered a private ecosystem that guarantee for anonymity, but it has come to light how, in reality, there are deanonymizing techniques that, if applied in the right context, can lead to user data leak (Beres et al., 2020).

In conclusion, user profiling on blockchain traceability platform is a subject that requires further studies. On one hand blockchain should be subject to the GDPR for customer data protection, and the blockchain providers must declare which data they will use, how and why, but on the other hands the writers' data must also be protected.

## Bibliography

- Ante, L. (2021). Smart contracts on the blockchain – A bibliometric analysis and review. In *Telematics and Informatics* (Vol. 57). Elsevier Ltd.
- Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: Safety and quality perspectives. In *Food Control* (Vol. 39, Issue 1, pp. 172–184). Elsevier BV.
- Badia-Melis, R., Mishra, P., & Ruiz-García, L. (2015). Food traceability: New trends and recent advances. A review. *Food Control*, *57*, 393–401.
- Béres, F., Seres, I. A., Benczúr, A. A., & Quintyne-Collins, M. (2020). *Blockchain is Watching You: Profiling and Deanonymizing Ethereum Users*.
- Bumblauskas, D., Mann, A., Dugan, B., & Rittmer, J. (2020). A blockchain use case in food distribution: Do you know where your food has been? In *International Journal of Information Management* (Vol. 52).
- Cachin, C., & Vukolić, M. (2017). Blockchain consensus protocols in the wild. *Leibniz International Proceedings in Informatics, LIPIcs*, *91*.
- Cornock, M. (2018). General Data Protection Regulation (GDPR) and implications for research. In *Maturitas* (Vol. 111, pp. A1–A2). Elsevier Ireland Ltd.
- Crosby, M., Pattanayak, P., Verma, S., & Kalyanaraman, V. (2016). Blockchain technology: Beyond bitcoin. *Applied Innovation*, *2*(6-10), 71.
- Demertzis, K., Rantos, K., & Drosatos, G. (2020). A dynamic intelligent policies analysis mechanism for personal data processing in the iot ecosystem. *Big Data and Cognitive Computing*, *4*(2), 1–16. https://doi.org/10.3390/bdcc4020009

- Galvez, J. F., Mejuto, J. C., & Simal-Gandara, J. (2018). Future challenges on the use of blockchain for food traceability analysis. In *TrAC - Trends in Analytical Chemistry* (Vol. 107, pp. 222–232). Elsevier B.V.
- Hackius, N., & Petersen, M. (2017). Blockchain in logistics and supply chain: trick or treat?. In *Digitalization in Supply Chain Management and Logistics: Smart and Digital Solutions for an Industry 4.0 Environment. Proceedings of the Hamburg International Conference of Logistics (HICL), Vol. 23* (pp. 3-18). Berlin: epubli GmbH.
- Inacio, I. (2021). Environmental costs related to cryptocurrency mining: ensuring that innovation does not happen at the expense of the environment.
- Kamilaris, A., Fonts, A., & Prenafeta-Boldύ, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. *Trends in Food Science and Technology*, *91*(July), 640–652.
- Kanoje, S., Girase, S., & Mukhopadhyay, D. (2014). User Profiling Trends, Techniques and Applications. In *International Journal of Advance Foundation and Research in Computer (IJAFRC)* (Vol. 1, Issue 1).
- Losasso, C., Cibin, V., Cappa, V., Roccato, A., Vanzo, A., Andrighetto, I., & Ricci, A. (2012). Food safety and nutrition: Improving consumer behaviour. *Food Control*, *26*(2), 252–258.
- Nakamoto, S. (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. *Https://Bitcoin.Org/Bitcoin.Pdf* . www.bitcoin.org
- Noizat, P. (2015). Blockchain electronic vote. In *Handbook of digital currency* (pp. 453-461). Academic Press.

- Olsen, P., & Borit, M. (2013). How to define traceability. In *Trends in Food Science and Technology* (Vol. 29, Issue 2, pp. 142–150).
- Olsen, P., & Borit, M. (2018). The components of a food traceability system. In *Trends in Food Science and Technology* (Vol. 77, pp. 143–149). Elsevier Ltd.
- Olson, K., Bowman, M., Mitchell, J., Amundson, S., Middleton, D., & Montgomery, C. (2018). Sawtooth: an introduction. *The Linux Foundation, Jan*, 26.
- Pearson, S., May, D., Leontidis, G., Swainson, M., Brewer, S., Bidaut, L., Frey, J. G., Parr, G., Maull, R., & Zisman, A. (2019). Are Distributed Ledger Technologies the panacea for food traceability? *Global Food Security*, *20*, 145–149.
- Powell, W., Foth, M., Cao, S., & Natanelov, V. (2022). Garbage in garbage out: The precarious link between IoT and blockchain in food supply chains. *Journal of Industrial Information Integration*, *25*.
- Rantos, K., Drosatos, G., Demertzis, K., Ilioudis, C., & Papanikolaou, A. (2018, July). Blockchain-based Consents Management for Personal Data Processing in the IoT Ecosystem. In *ICETE (2)* (pp. 738-743).
- Scuderi, A., Foti, V., & Timpanaro, G. (2019). The supply chain value of pod and pgi food products through the application of blockchain. *Calitatea*, *20*(S2), 580-587.
- Stifter, N., Judmayer, A., Schindler, P., Kern, A., & Fdhila, W. (2021). What is Meant by Permissionless Blockchains?. *IACR Cryptol. ePrint Arch.*, *2021*, 23.
- Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. In *2016 13th international conference on service systems and service management (ICSSSM)* (pp. 1-6). IEEE.

- Tian, F. (2017). A supply chain traceability system for food safety based on HACCP, blockchain & Internet of things. In *2017 International conference on service systems and service management* (pp. 1-6). IEEE.
- Vranken, H. (2017). Sustainability of bitcoin and blockchains. In *Current Opinion in Environmental Sustainability* (Vol. 28, pp. 1–9). Elsevier B.V.
- Vukolić, M. (2015). The quest for scalable blockchain fabric: Proof-of-work vs. BFT replication. In *International workshop on open problems in network security* (pp. 112-125). Springer, Cham.
- Wachter, S. (2018). Ethical and normative challenges of identification in the Internet of Things. *Living in the Internet of Things: Cybersecurity of the IoT – 2018*
- Zhang, A., Mankad, A., & Ariyawardana, A. (2020). Establishing confidence in food safety: is traceability a solution in consumers' eyes? *Journal Fur Verbraucherschutz Und Lebensmittelsicherheit*, *15*(2), 99–107.
- Zhao, J. L., Fan, S., & Yan, J. (2016). Overview of business innovations and research opportunities in blockchain and introduction to the special issue. *Financial innovation*, *2*(1), 1-7.

## Use case description: Saporare and S|Trace

The use case study that is part of this study is an ecommerce of traditional Italian food products provided with blockchain-based digital traceability, both owned by Franceschi srl. Franceschi srl started an innovative idea which is composed by two parts that work together: an e-commerce of traditional Italian product named Saporare – Italian Food Boutique and a blockchain-based traceability platform named S|Trace – Track Your Business.

### Aim of the project

The idea behind this working scheme is that the products sold on Saporare are traced with S|Trace, but the blockchain traceability platform is tailored to be flexible enough to be adapted for any other third part that need certification for their supply chain, product or service, both agrifood and not. S|Trace itself is composed by two parts, a webapp for data entry and management, and a real blockchain. This project started in the middle of 2020 with a first version of the e-commerce and the webapp, initially meant to work less close than they do now and a different version of the webapp. The system is a new build, with no pre-existent internal traceability softwares, whereas it is the webapp developed together with the blockchain that will work as a traceability software, warehouse stock inventory, management software and customer interface. Consumers can access to the data through a QR code printed on the packaging of each traced product as the blockchain used is a public permissioned one, with some data that may be encrypted and not shown to the public.

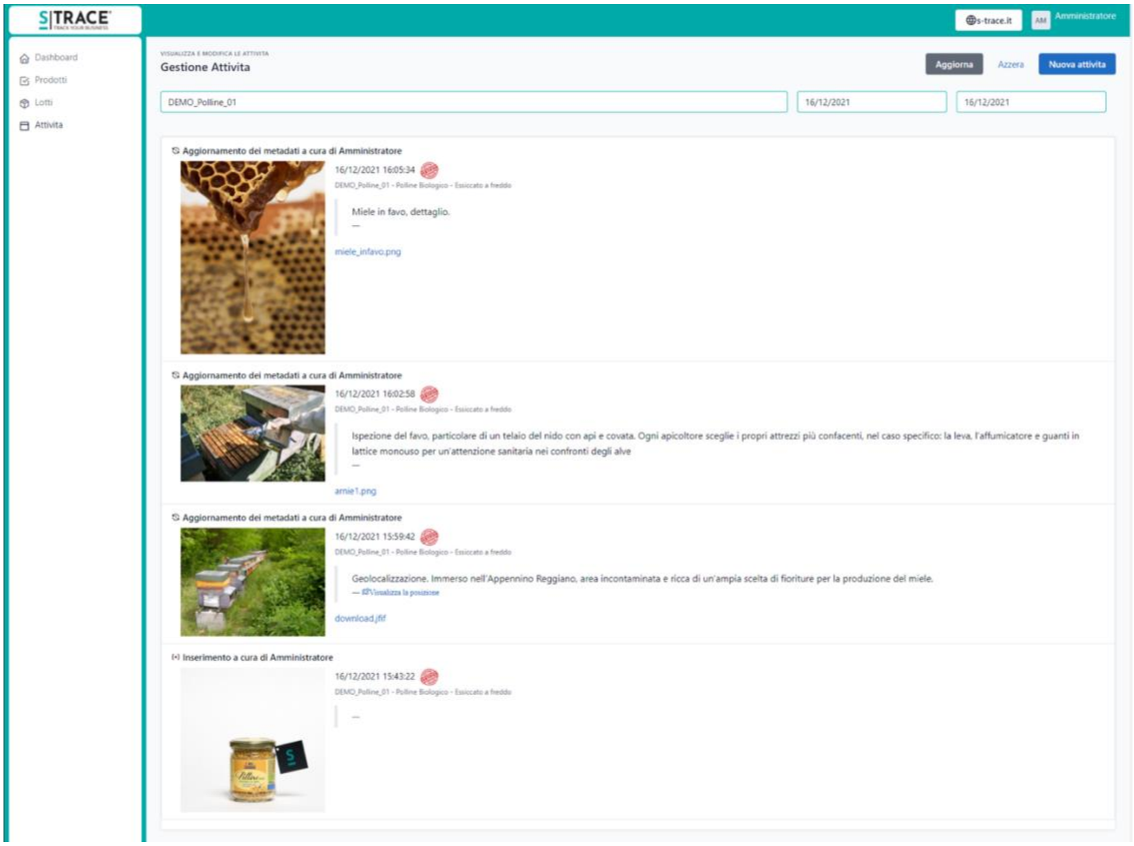
This study is on Franceschi’s Saporare and S|Trace system, its aim, how it is different from other use cases and the impacts it may have.

## Advantages in blockchain traceability adoption

By choosing to use blockchain to trace the products sold on the ecommerce, the consumers can be more certain of the origin of the products that they are buying and this imply that they will have an increased power of choice, as each step of the supply chain will be shown in the webapp interface once the QR code is scanned (Fig 1).

Blockchain applied to the digital traceability of the food supply chain ensure a different experience for the customers by directly involving them in the control of the origin on the food. Furthermore, consumers are more involved thanks to the story telling than can be added and shown by the producers, which also opens new marketing possibilities for them.

Producers can include geo-localization with a tailored precision, as some may choose to use a precise location and some may prefer to use a radius-like area, which dimension is at the discretion of the producer.



VISUALIZZA E MODIFICA LE ATTIVITA

Gestione Attivita

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Aggiornamento dei metadati a cura di Amministratore

16/12/2021 16:05:34

DEMO_Polline_01 - Polline Biologico - Essiccato a freddo

Miele in favo, dettaglio.

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Aggiornamento dei metadati a cura di Amministratore

16/12/2021 16:02:58

DEMO_Polline_01 - Polline Biologico - Essiccato a freddo

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Aggiornamento dei metadati a cura di Amministratore

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Geolocalizzazione. Immerso nell'Appennino Reggiano, area incontaminata e ricca di un'ampia scelta di fioriture per la produzione del miele.

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Inserimento a cura di Amministratore

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Fig. 1. Screenshot of the webapp interface. Each step is time-stamped and the timestamp is shown to the customers. The red dot on the side of each stamp indicates that the data have successfully been registered on the blockchain. Any other information or photo can be attached to add more information, improve customer experience and marketing possibilities.

S|Trace can also valorizes producers, improving their visibility, their marketing possibilities and it can help them in case of controls by control entities as all the documents regarding the traceability of a batch are saved in an immutable and tamper proof system, available at need. S|Trace is useful for any kind of certification, including non-agrifood ones such as ISO certification and others.

S|Trace integrates with the management software in order to avoid any possible data duplicates, such as products or batches, but it can also work in the opposite way, as it is planned that S|Trace itself could integrate data on the pre-existent management software.

Finally, S|Trace includes the possibility and the technology for user profiling: for the moment it is not active.

### Traced products and case study

The complete name of the ecommerce is "Saporare: Italian Food Boutique" and its main aim is to sell high-end traditional Italian products, such as wine and spirits, olive oil, honey and pollen, balsamic vinegar and other condiments, all from medium and small producers and cooperatives. The first case study that has been developed on S|Trace is on the complete traceability of honey and pollen from a social cooperative. Recently, pollen has become more and more popular as dierary supplement and now more beekeepers are selling both honey and pollen. In particular, the *Castanea sativa* pollen sold on Saporare is dried at low temperature (close to the natural beehive internal temperature), a technique that allows the pollen to maintain intact nutrient values and sensory characteristics (Colotta and Porporato, 2015).

Regarding honey, it is a kind of food that would benefit from improved traceability system. Honey is the result of the transformation of nectar and other sugary substances (like honeydew) that bees collect and transform as a food storage for the seasons in which there is scarcity of fresh nutriment. It comes mainly from the farmed western honeybee, *Apis mellifera*, other *Apis sp.* (like *A. cerasana*) and few other genera in tropical regions. Honey is composed almost totally by sugars (70% monosaccharides and 10-15% disaccharides), but the remaining part has a considerable variability that derives from the floral and geographical variations and it can contain some distinctive elements such as pollen. Globally the honey production assessed around 18 billion dollars in 2018 and it is expected to grow over 25 billion by 2025 (Rao et al., 2016). The EU is the second most important producer, after China, with a slowly increasing total production from the 250 thousand tons in 2015 to the 280 thousand tons in 2020 coming from around 19 millions beehives (EU, 2021).

Honey production may be scarce due to environmental conditions, climate change and honeybee pathologies, such as Colony Collapse Disorder (CCD) or *Varroa destructor*, two serious problems that affect bee colonies with an high impact on their lifespan and honey production (Nazzi and le Conte, 2016; VanEngelsdorp et al, 2017).

To compensate for scarce production or to increase honeybee colonies yield, producers may iterate incorrect practices. The most common is to adulterate the honey by adding sugars and sweeteners a practice that evolved from the most basic addition of sugar and water to the addition of vegetable syrups (such as rice, maize and wheat syrup) that mimic natural honey sugar composition to make harder the detection of this fraudulent practice. The second adulteration is to feed sugar directly to the bees during the nectar collection period: this adulteration is much harder to detect as the sugars will undergo the same transformations as natural floral nectar (Aries et al, 2016).

To detect these frauds, different techniques may be applied, from the chemical composition analysis through thin-layer or gas chromatography to more sophisticated analysis such as carbon isotopes analysis. Honey also contains simple sugars and other nutrients that are easier to digest, as well as natural antibacterial properties that adulterants do not contain. The adulterants may result in several adverse health effect, from an increase of body weight and sugar blood to more serious effects like fatty liver, acute and chronical kidney injuries and elevate visceral fat pads (Fakhlaei et al, 2020).

In 2015 the Joint Research Center of the European Union analysed a sample of EU and extra EU commercial honeys and had found that a considerable 14% of the EU sample contained sugars of foreign origin, as well as 20% of the extra EU honey; also, a further 10% was considered suspicious of adulterations (Aries et al, 2016).

Another important analysis is the pollen analysis of the honey. Honey always contains pollen grains (mainly from forage plants for the bees) as well as element that are distinctive for honeydew, that can provide for an accurate fingerprint of the honey. This means that different honeys from different geographical regions have a different pollen composition, and this can be used to assess the real origin. Furthermore, some honeys are filtered: this practice is not illegal, but it is usually associated with fraudulent practices aimed to prevent the identification of the real origin of the products (von der Ohe, 2004).

For all the issues listed above, an improved traceability of honey may greatly advantage righteous producers and this use case represent an example for further studies and implementation of digital traceability of honey.

In the future, the goal is to trace every product sold on Saporare ecommerce, as, thanks to its scalability and versatility, S|Trace can be applied to trace any supply chain. Among the partners there are olive oil, wine and cheese producers, all products that will benefit from an improved supply chain as all of them are included both in the list of products in need of a better traceability and subjects to frauds.

Olive oil is listed as one of the most counterfeited and adulterated products (Moore et al, 2010), with the most common adulteration deriving from a misleading product sold under the label of extra virgin olive oil, but containing at least partially other olive oil (such as common olive oil), fraudulently mislabelled declaration of origin (e.g. as produced in a Italy but actually containing oil from other countries – such as Turkey) or sold as organic but containing chemical pesticides residuals in a considerable quantity (Jurado-Campos et al., 2019; MIPAAF, 2021). Olive oil is among the products that will certainly benefit from a digital traceability, as shown by different studies and project already working (Arena et al, 2019).

Wine as well is listed as one of the most counterfeited products. This beverage has a remarkable market, especially the traditional product covered by origin declaration, such as DOC or DOCG. Ministero Delle Politiche Agrare e Forestali (MIPAAF) reported 32 cases of counterfeiting in the EU, which are only the tip of the iceberg of the Italian sounding. Among the wines, in recent years prosecco wine resulted being the most counterfeited Italian product, which is mainly because a sparkling wine with uncertain origin was sold recalling the traditional Italian name or as a traditional Italian product (MIPAAF, 2021). Wine is a product that, for its type of supply chain, is not the correct example of the application of a blockchain (Patelli and Mandrioli, 2020), but it would certainly benefit from an improved and secure traceability system.

This comprehensive traceability goal will not be achievable in a short time as the producers need time to learn how to use and adapt to digital traceability. S|Trace, however, is thought and designed to prioritize easier use compared to other similar software and to prior version of this software, and to be adapted to the user instead of being the user that must adapt to the system. The user-friendliness has been highly appreciated by administrators and, most importantly, workers of the partner companies.

## Technologies

The webapp has been developed in C# program language in .NET Core framework; it has been designed to upload the entered data on the blockchain through smart contracts. The graphic style of the webapp has been developed on CSS style sheet language. For data storage, the webapp uses an SQL database.

The blockchain is based on Ethereum blockchain and works on a separate fork. Smart contracts have been developed using Solidity, the primary programming language on Ethereum.

S|Trace works on a fork of Ethereum Virtual Machine (EVM), the virtual computer on which Ethereum smart contracts are run. Thanks to its architecture, smart contracts that are executed in EVM are secure and trustworthy (Hirai, 2017). The choice of Ethereum was made following some aspects, such as the versatility of the system, the reduced environmental impact of Ethereum blocks validation system (Proof of Stake) and it is a public and easily accessible blockchain.

Ethereum security and tamper proofness relies on Proof of Stake (PoS) instead of Proof of Work (PoW), a validation system that allows Ethereum to be less impactful on the environment than the other traditional PoW blockchain. PoW is the traditional mechanic behind Bitcoin and other cryptocurrencies; it is based on a series of complicate mathematical operations that have to be complete both to create a new block and to generate new unit of a cryptocurrency (a process called mining). PoW is an ideal architecture for how bitcoin work, but if on one hand ensure security, on the other hand is very slow and energy consuming (Sakamoto, 2008). Mining is also based on PoW, an activity that is so energy intensive that recently this energy consumption has become a serious problem: Kosovo recently banned bitcoin mining due to its high energy cost as a result of an increase of the energy production costs (Reuters, 2022).

PoS, instead, is faster, less energy expensive and makes a PoS-relying blockchain more scalable and suitable for supply chain traceability. It relies on a different mechanism, instead being directly dependent to hardware it is based on the concept that the nodes that possess more unit of a cryptocurrency is reliable and it has no intent of tamper the system (King and Nadal, 2012; Vukolic, 2015). PoS make Ethereum both less energy-greedy and more suitable for different application than the PoW blockchain, making the perfect base-technology for the implementation of S|Trace.

### Link with the real world

Regarding the existent link between the blockchain and the real world, there are two aspects that have to be considered. The first is the complex subject of producers’ data reliability. The data stored on the blockchain are reliable, immutable and tamper-proof, but the data may not correspond to the reality. This problem generally affects blockchain applications (Shahid et al, 2020), but a possible solution is a cross control made by control entities (that oversee disciplinaries and production methods, as well as control by chemical and biological analysis), Saporare implicit control on the supply chain (which is mainly on the reliability of the data themselves) and the consumers, who actively access the data to control for what they bought.

The second issue is related to the access to the blockchain, easily solved by a provided QR that is applied on the packaging of the products as they will partially or totally be sold under Saporare label as shown on the website, whilst the products that will not be re-labelled will be provided with a QR, leading to S|Trace webpage, that will be a sticky label or a thin carton label attached to strategic part of the packaging, such as bottle neck or vase cap: this can also be an important element to characterize Saporare packaging (Butkeviien and Stravinskientelion 2008).

Francheschi srl will also organise planned audits to verify that what the producers declare match the reality. These audits will be held periodically by certified professionals who have considerable knowledge for each traced supply chain, that are meant to certify the production methods at the very least as a further guarantee for the consumers. Franceschi srl does not have the responsibility for the data that the producers will declare, it guarantees for the existence of the production but the producers themselves will have the legal liability for the entered data. S|Trace is, in this case, a mean for the guarantee of the data and it contributes to give more responsibility to the producers and it will also contributes to improve trust in this system.

### Saporare and S|Trace supply chain

Saporare and S|Trace represent a unique case in blockchain application environment. If it is true that S|Trace can be used to trace the products of a single producers, Saporare acts as a third part in a supply chain. It certifies the products sold on the ecommerce without substituting to any other disciplinary or controller (such as EFSA) (Fig 2).

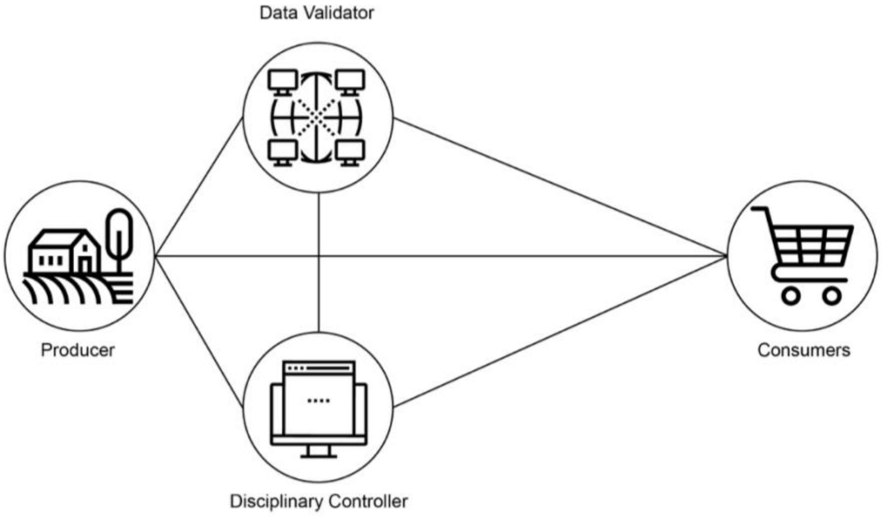

Fig 2. Saporare supply chain is composed by 4 actors that interact together by using S|Trace traceability system. Saporare acts as a third part in the supply chain, becoming a data validator without substituting to any disciplinary controller or other control entities, that can access the data stored on S|Trace blockchain in case of a control or the producers can show the data to the control entities in case of need. At last, consumers can control all the steps in the supply chain by accessing to the system through a QR. This supply chain is the perfect example of a justified blockchain use.

There are three main kind of account that are intended to be created: Admin, Wallet authentication and Pin Code access (Tab 1).

The general management, programming and setting operation of S|Trace and the webapp are done by the admin, account with unlimited access and privilege. The admin is also able to create other accounts and it oversees the tailored setting of the blockchain steps on which entry data in function of every supply chain traced on the system (these steps should reflect the steps of the supply chain and the producers' needs).

The authentication on the blockchain is possible through a wallet. Each user/producer has its own specific wallet used for authentication, thus only authenticated users can write data on the permissioned Ethereum blockchain, but being public everyone can read the data: some data are always shown, such as the origin and the time-stamp, but others can be encrypted to the public, like selling price or the precise location of the beehives. Another key feature of the app is the possibility to access to different levels in function of the user, as some may have admin-like privileges and others can only write specific data.

The webapp also include a simplified access procedure for quick data entry on selected categories or for simple workers: they cannot create a new product or a new batch, but through pin code (that can be set from the main account associated with a specific wallet if it possesses the privilege) they can easily and quickly access to register some data such as location or specific production steps or adding subsidiary information like adding photos and other documents. All this process can be tailored on every supply chain traced on S|Trace, starting from the privilege guaranteed by the wallet associated with a producer to the data addable using only the pin code.

| Type of Account | Operations allowed and Privilege |
|---|---|
| Admin | Unlimited Access. Admin can create and eliminate every other account. Admin can set the webapp to any specific need of the Wallet-Authenticated users and create the link between webapp and Ethereum blockchain. |
| Wallet Authentication | Creation and management of new products; new batch for each product; general management through the dashboard; activity management and search. If it is permitted by the admin, the creation of the Pin Code. |
| Pin Code | Simple and quick operations, such as the update of the supply chain steps or an image attachment. |

Tab 1. Allowed operation on S|Trace webapp in function of the user privilege on S|Trace.

### Costs for the system

The costs for both Saporare and S|Trace can be divided in three sections. Any promotion or marketing cost will not be taken in account as it may greatly vary following the general success, the promotion needed on the social network and other unpredictable variables.

The project costs represented the first main step to overcome for Franceschi srl, a cost that is mainly related to the writing and development of Saporare website the two components of S|Trace, the webapp and the smart contracts that connect to Ethereum blockchain. These costs are necessary to develop a complex system like S|Trace, but this architecture is also necessary to ensure its reliability. Furthermore, they are one-off costs that are amortised on the customers with a slight price increase and on the producers, that pay a fee to utilize S|Trace.

Another cost is the server usage and rent, as it is lower and thus more affordable than the building and maintenance of internal servers. This is a fixed cost which can be considered constant as long as the server rent would not have any unexpected increase and can be divided again on both consumers and producers.

The last is the cost for every transaction, a variable cost that depends on the number of transaction and on the cost itself. First, Ethereum has also one of the highest transaction costs among all the blockchains suitable for traceability especially if compared with Hyperledger, the other well-known blockchain platform used for traceability, which basically has no cost except for the energy cost. Second, a remarkable part of the cost is related to the cryptocurrency market exchange, which makes this voice highly difficult to predict and can also undergo to considerable and remarkable variation that can increase or decrease this cost in a very short time.

This influence the cost of transaction for S|Trace as every new block, even if it is on the S|Trace EVM fork, is created as if it was a crypto transaction between two users, in this case the Admin and the Wallet authenticated user. Ethereum has a fee for every transaction, called “gas”, which is a pre-specified execution cost that has to be paid for the creation of the new block. This cost is highly variable itself and it depends on the amount of ETH transferred between two users, which is the most common type of transaction registered on Ethereum. The second type of transaction depends on the execution of a smart contract and, depending on the complexity of the smart contract itself, it varies: nevertheless, its cost is significantly higher than a simple transaction (Donmez and Karaivanov, 2022). S|Trace is based on smart contracts and every transaction is a 0 ETH transfer, thus the cost depends entirely on the gas requirement for the execution of the internal smart contracts, a cost that is nonetheless considered affordable.

## Similar projects and literature review

Franceschi srl project has a distinctive characteristic that makes unique this working use case: Saporare certifies for the third part producers, by using S|Trace, without substituting to the producers themselves but valorising them and their products. There are some other blockchain application to the e-commerce, but none has nothing similar to this peculiar mechanism. Blockchain-based ecommerce are focused on information sharing, co-certification, and storage transaction for all participants on the network (Nijeholt et al, 2017). Dhore and Mishra (2020) theorized a possible application of Ethereum blockchain to the ecommerce, but instead of a declaration of origin they proposed a system based on Ethereum smart contracts that certifies for a successful delivery, together with a payment in ETH (the specific cryptocurrency on which payment in Ethereum are based on). This is certainly a valid and interesting system, but it does not solve any problem connected to the traceability of the goods.

Many other studies involve another crucial point that connects ecommerce and blockchain, which is the transaction method. A considerable number of studies focused on potential blockchain applications for secure and traceable payments for business to business (B2B), control over transactions and business protection, which are all trading-related aspects

(Mohammed et al, 2021; Treiblmaier and Sillaber, 2021), or systems to improve security and reliability of the producers and the product grading (Yang et al, 2019).

Other solutions are focused on an interesting aspect that is the security aspects related to the IoT devices. Based on smart contracts that authorize the access to a set of data for the IoT devices, important as these devices are increasingly present in many supply chains and when there are two or more actors that may not trust each other, these solutions can provide for a safe system for the control of the supply chain management is required (Qun et al., 2021). Finally, some solutions mention the possibility to use a blockchain based supply chain management and as an anti-counterfeit strategy to ensure transaction security (Lee and Yeon, 2021). Some of them are specifically made to ensure security and traceability for the vendors on ecommerce platforms, like Amazon Web Services (AWS), even if does not provide for further details (Jiang and Chen, 2021; Perboli and Bagozzi, 2019). However, such applications can be considered as a purposely implemented application of a blockchain to protect both customers and producers, but all these example lack in the unicity of Saporare-S|Trace, as there are no third part entity that certify for the producers and the sold product.

In conclusion, some of these use cases are focused on the transactions, the payments and the secure management of an ecommerce, while others are more related to supply chain traceability of the producers in an ecommerce environment, which, again, is different than the product certification and producer value appreciation given by Saporare-S|Trace structure. This project can be considered as the perfect use-case to describe the real need for a proper permissioned blockchain applied to the food supply chain traceability.

## Bibliography

- Arena, A., Bianchini, A., Perazzo, P., Vallati, C., & Dini, G. (2019). BRUSCHETTA: An IoT blockchain-based framework for certifying extra virgin olive oil supply chain. *Proceedings - 2019 IEEE International Conference on Smart Computing, SMARTCOMP 2019*, 173–179.
- Aries, E., Burton, J., Carrasco, L., de Rudder, O., & Maquet, A. (2016). *Scientific support to the implementation of a Coordinated Control Plan with a view to establishing the prevalence of fraudulent practices in the marketing of honey Results of honey authenticity testing by liquid chromatography-isotope ratio mass spectrometry*. https://ec.europa.eu/jrc
- Butkeviien, V., & Stravinskientelion, J. (2008). *Impact of Consumer Package Communication on Consumer Decision Making Process* (Issue 1).
- Ching-Nung Yang, Y.-C. C. S.-Y. C. S.-Y. W., & Institute of Electrical and Electronics Engineers. (2019). A Reliable E-commerce Business Model Using Blockchain Based Product Grading System. *2019 the 4th IEEE International Conference on Big Data Analytics*.
- Dhore, V. D., & Mishra, N. (2020). Supply Chain Management in E-Commerce Using Blockchain. In *IC-BCT 2019* (pp. 57-67). Springer, Singapore.
- Donmez, A., & Karaivanov, A. (2022). Transaction fee economics in the Ethereum blockchain. *Economic Inquiry*, *60*(1), 265-292.

- EU, 2020. Detailed information on honey production in the European Union. Available at https://ec.europa.eu/info/food-farming-fisheries/animals-and-animal-products/animal-products/honey_en
- Fakhlaei, R., Selamat, J., Khatib, A., Razi, A. F. A., Sukor, R., Ahmad, S., & Babadi, A. A. (2020). The toxic impact of honey adulteration: A review. In *Foods* (Vol. 9, Issue 11). MDPI AG.
- Hirai, Y. (2017). Defining the ethereum virtual machine for interactive theorem provers. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *10323 LNCS*, 520–535.
- Jiang, J., & Chen, J. (2021). Framework of blockchain-supported e-commerce platform for small and medium enterprises. *Sustainability (Switzerland)*, *13*(15).
- Jurado-Campos, N., García-Nicolás, M., Pastor-Belda, M., Bußmann, T., Arroyo-Manzanares, N., Jiménez, B., Viñas, P., & Arce, L. (2021). Exploration of the potential of different analytical techniques to authenticate organic vs. conventional olives and olive oils from two varieties using untargeted fingerprinting approaches. *Food Control*, *124*.
- Lee, H., & Yeon, C. (2021). Blockchain-based traceability for anti-counterfeit in cross-border e-commerce transactions. *Sustainability (Switzerland)*, *13*(19).
- MIPAAF. (2020). *Report Attività 2020*. Available at https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/16773
- Mohammed, S., Fiaidhi, J., Ramos, C., Kim, T. H., Fang, W. C., & Abdelzaher, T. (2021). Blockchain in eCommerce: A Special Issue of the ACM Transactions on Internet of Things. *ACM Transactions on Internet Technology*, *21*(1).

- Moore, J. C., Spink, J., & Lipp, M. (2012). Development and Application of a Database of Food Ingredient Fraud and Economically Motivated Adulteration from 1980 to 2010. In *Journal of Food Science* (Vol. 77, Issue 4).
- Nakamoto, S. (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. Available at *Https://Bitcoin.Org/Bitcoin.Pdf*.
- Nazzi, F., & le Conte, Y. (2016). Ecology of Varroa destructor, the Major Ectoparasite of the Western Honey Bee, Apis mellifera. In *Annual Review of Entomology* (Vol. 61, pp. 417–432). Annual Reviews Inc.
- Nijeholt, H. L. À., Oudejans, J., & Erkin, Z. (2017). DecReg: A Framework for Preventing Double-Financing using Blockchain Technology. *BCC 2017 - Proceedings of the ACM Workshop on Blockchain, Cryptocurrencies and Contracts, Co-Located with ASIA CCS 2017*, 29–34.
- Patelli, N., & Mandrioli, M. (2020). Blockchain technology and traceability in the agrifood industry. *Journal of Food Science*, *85*(11), 3670–3678.
- Perboli Fabio, & Bagozzi Guido. (2019). *Implementazione della blockchain nella supply chain di un e-commerce retailer*.
- Qun Song, A., Chen, Y., Zhong, Y., Lan, K., Fong, S., & Rui Tang, B. (2021). A Supply-chain System Framework Based on Internet of Things Using Blockchain Technology. *ACM Transactions on Internet Technology*, *21*(1).
- Rao, P. V., Krishnan, K. T., Salleh, N., & Gan, S. H. (2016). Biological and therapeutic effects of honey produced by honey bees and stingless bees: A comparative

review. In *Revista Brasileira de Farmacognosia* (Vol. 26, Issue 5, pp. 657–664). Sociedade Brasileira de Farmacognosia.

- Reuters (2022). Kosovo bans cryptocurrency mining to save electricity. Available at https://www.reuters.com/markets/commodities/kosovo-bans-cryptocurrency-mining-save-electricity-2022-01-04/
- Shahid, A., Almogren, A., Javaid, N., Al-Zahrani, F. A., Zuair, M., & Alam, M. (2020). Blockchain-Based Agri-Food Supply Chain: A Complete Solution. *IEEE Access*, *8*, 69230–69243.
- Treiblmaier, H., & Sillaber, C. (2021). The impact of blockchain on e-commerce: A framework for salient research topics. *Electronic Commerce Research and Applications*, *48*. https://doi.org/10.1016/j.elerap.2021.101054
- VanEngelsdorp, D., Traynor, K. S., Andree, M., Lichtenberg, E. M., Chen, Y., Saegerman, C., & Cox-Foster, D. L. (2017). Colony Collapse Disorder (CCD) and bee age impact honey bee pathophysiology. *PLoS ONE*, *12*(7).
- von der Ohe, W., Persano Oddo, L., Piana, M. L., Morlot, M., & Martin, P. (2004). Harmonized methods of melissopalynology. *Apidologie*, *35*(Suppl. 1), S18–S25.

## Consumer opinion on blockchain technologies and improved traceability

Blockchain has been recognized as a new disruptive technology that can revolutionize financial transaction (Wörner et al, 2016), insurance (Mainelli and Manson, 2016), voting (Moura and Gomes, 2017) and it has many other application fields. Blockchain can also be successfully applied to supply chain traceability (Berneis and Winkler, 2021), which may change the way in which traceability has worked, and only recently it has been possible to see successful applications (including the case study Saporare and S|Trace described in this research).

However, a problem that can limit the adoption of blockchain technology is the cost increase (Liu, 2022) for the companies that implies the project building, the server buying or renting and working and maintenance costs. Even if these costs may be less relevant that they may seem (Longo et al, 2020), a product provided with blockchain technology traceability or, in general, digital traceability is expected to have a higher price than a non-provided one. This cost increase must be considered if a company decides to adopt digital traceability, as well as what the competitors offer and the value of more transparency that digital traceability implies. To plan a successful blockchain traceability project, the previous factors must be balanced by an increased interest for the customer toward digital traceability, which should lead to a business advantage that should distinguish the company from the competitors (Garaus and Treiblmaier, 2021).

Consumer opinion is important, as it can provide for useful information on their preference, their attitude, their willingness to spend money on a product or a product category instead of another or their attitude toward a production method, such as organic or conventional food

(Ismael and Ploeger, 2020) or new food that can potentially disrupt a market, such as the introduction of the insects as a food source: this is a peculiar case, the acceptance is low, but it may have a positive impact on the environment as a sustainable source of protein with a low impact (Simeone and Scarpato, 2022). Consumers can also influence politics and marketing as their preference can drive the companies to adopt production methods that respect the ideas that consumers have: for example it can influence for the adoption of more respectful practices that guarantee less impact on the environment to mitigate climate change (Robertson and Barling, 2013).

To assess the interest of consumers toward digital traceability, a questionnaire has been prepared, with questions regarding the knowledge that they possess and the interested they have in having improved traceability systems, which shopping preference they have (where they buy food), and if there are food categories (e.g. meat, fish, dairy and others) that require an improved traceability. Finally, the questionnaire included a specific question to evaluate the willingness of the customers to spend more for a product provided with digital traceability.

### Questionnaire design and promotion

The questionnaire here presented was designed in 2019, after a bibliographic analysis that showed a lack in consumer opinion. It has been tailored to understand the consumers' interest and knowledge towards the concept of traceability, if they have any knowledge regarding blockchain technology (with no further specifications, thus also having heard about blockchain for the cryptocurrencies was accepted), which shopping preferences they have (where do they shop for food and if they would be more incline to buy products provided with digital traceability systems) and the suggestion of food categories (e.g. meat, fish and others) currently requiring an improved traceability. Finally, their willingness to spend more to buy food provided with digital traceability was evaluated as an indication for the acceptance and interest towards the application of the blockchain on the supply chain traceability.

It was promoted during multiple occasions in presence in 2019. For the first events the questionnaire has been physical, but it was already designed to work in an online version using Google form, to ease the collection of the answers, to improve the number of compilers and to ease data entry. then, in January 2020 the pandemic exploded, and several events have been cancelled or transformed in their online version to prevent further infections.

In order to increase the to collect answers, the promotion of the online version has been done through social media, in particular consumer and blockchain-related Facebook groups and Whatsapp, then with articles on magazines that focus on food-related areas, such one that publish articles on food and food production subjects and a bovine breeding and nutrition bimonthly, both in online and physical versions. Thanks to these methods, the total number increased from the around 160 compilers initially collected to the final number of 502 single respondants.

### Profiling questions

The first questions asked were specifically for user profiling.

The first question is about the age (Fig 1) younger age class is 18-25 as the questionnaire was not intended to be compiled by underage. The youngers are usually focused on studying and finding a job, but they usually are aware of environmental problem and for such reason they may be more aware of the environmental impact of the food supply chain, thus mindful of the origin of the food.

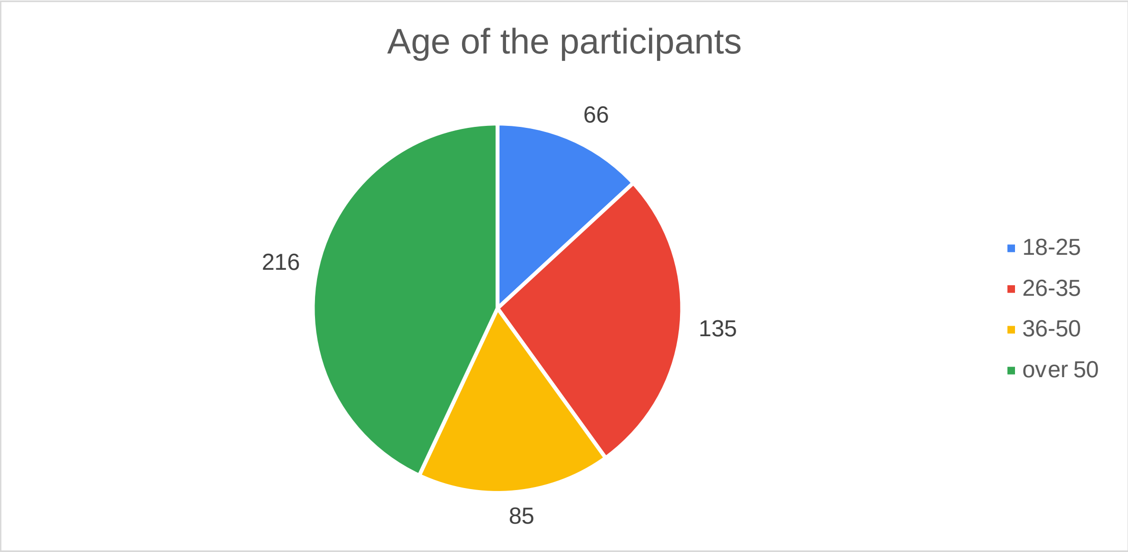

Fig. 1. Age of the partecipants.

The respondants are mainly over 50 years old (YO), with 216 answers, accounting for the 43% of the total. The second age class is the 26-35 YO (accounting for the 26.9%), then 36-50 YO (with the 16.9% of the answers) and 18-25 YO (with the 13.1%).

Second question is about the gender (Fig. 2), and to complete the general user profiling, the gender has been compared with the age (Fig. 3).

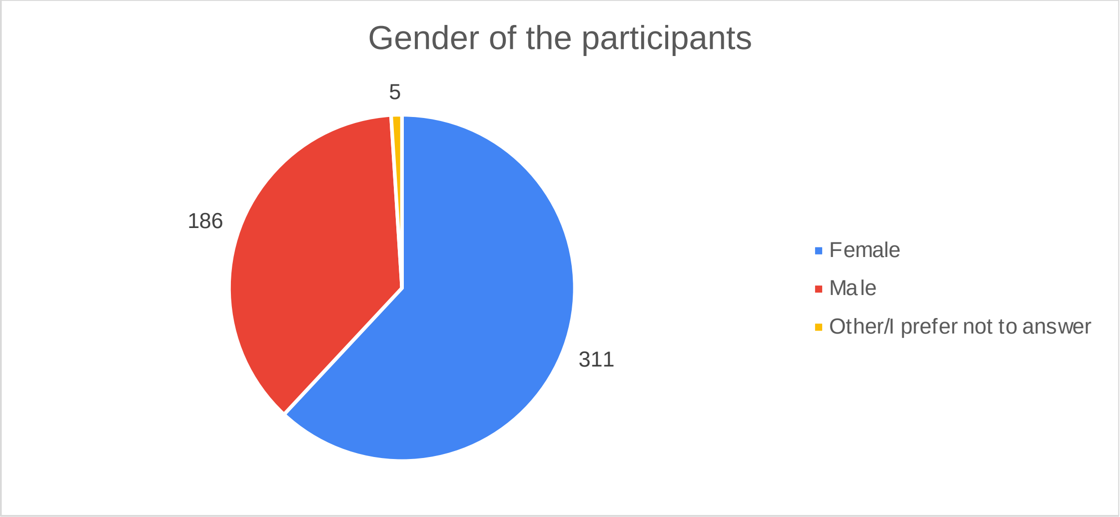

Fig. 2. Gender of the participants.

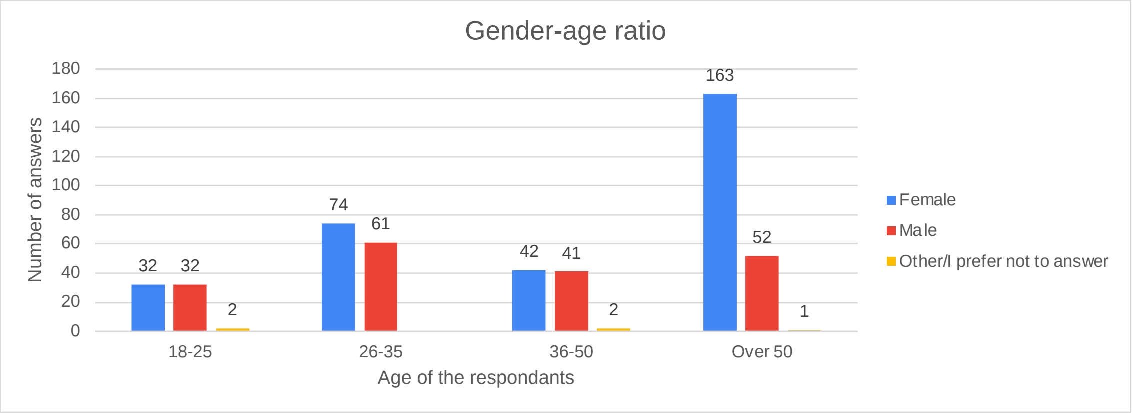

Fig. 3. Gender-age ratio.

The most common respondents of this questionnaire are women over 50 YO, which represent the highest number of respondents in total with 163 single compilers. Second and third class are women and men of the 26-35 YO class, with a slight difference of 13 more single compilers from these last two. Finally, there are men Over 50 YO and the two class

18-25 and 36-50 are equally represented and in conclusion there are 5 respondents who declared that preferred not to answer to the gender question.

The third profiling question is about the instruction level (Fig. 4). High school diploma and degree were the first and equally represented instruction level classes and they totally represent the 86.8% of the respondents. In the Degree class is included any kind of degree of any discipline, both bachelor and master degree or 5 years one-cycle degree. Post-Degree, which includes PhD and other is the third class, and the last is the middle school level instruction class, which is meant to include elder people that did not completed high school and not underage teenagers as they usually do not shop for food as they live with their parents.

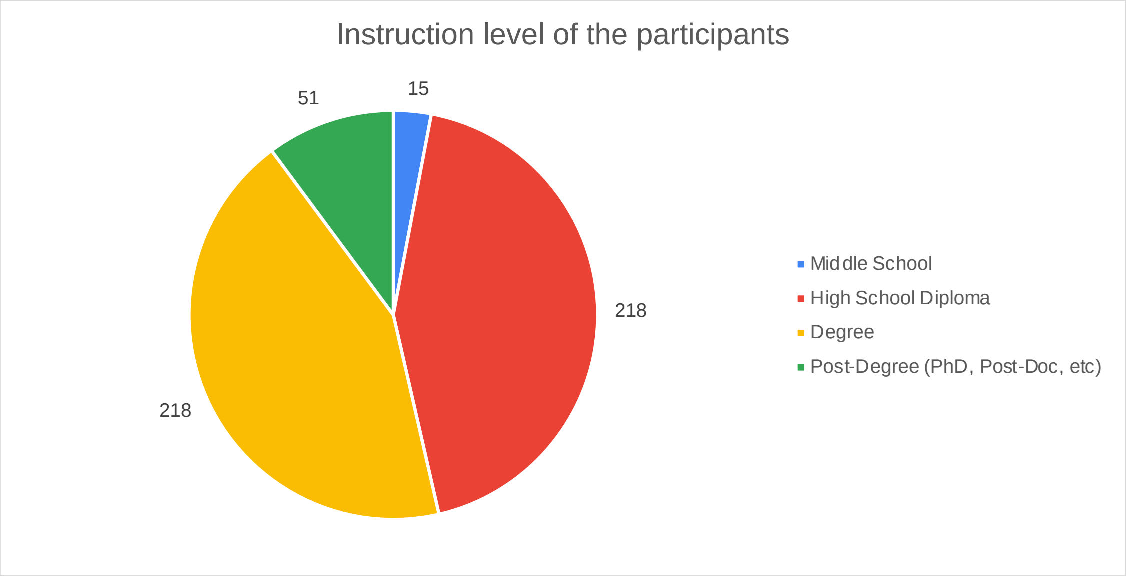

Fig 4. Instruction level of the participants.

The instruction-age ratio (Fig. 5) reveals that if High School diploma holders are mostly over 50, the Degree is more equally distributed, even if most of the degree-holder compilers are in the 26-35 YO. In the class 36-50 YO the high school diploma and degree holder are well balanced, as well as in the 18-25 YO category, even if the majority of them is still studying to get a degree or a post-degree. This situation is a good perspective of the instruction level in Italy, as from the 1950 to the recent years the number of graduated people is greatly increased due to an improved economic situation of the country that allowed many young people to spend more years in school for a better specialization (Istat, 2011; Istat, 2022).

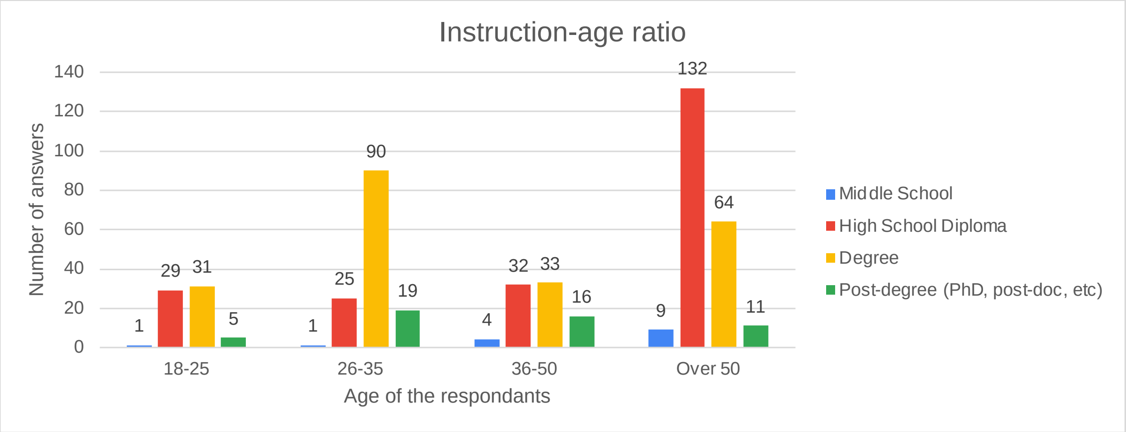

Fig. 5. Instruction-age ratio. The most represented class is the Over 50 YO with an high school diploma, followed by the 26-35 YO with a degree.

The last of the profiling question is the region of origin (Fig. 6). The vast majority of the compilers come from Emilia-Romagna (310 in total, accounting for the 61% of the compilers), followed by Piemonte and Lombardia, both with 41 compilers, representing the 8.2% each. Puglia and Campania are the fourth and fifth regions for number of respondents, with 20 and 14 answers, accounting for the 4% and the 2.8% of the total. Apart from these regions, the others are less represented, but at least one person for each region compiled the questionnaire, except for Valle D'Aosta, which is the only region that is not represented at all. The reason may be due to the fact that Valle D'Aosta is the smallest region of Italy and the one that has less inhabitants, slightly after Molise (Istat, 2021), from which only one respondent compiled the questionnaire.

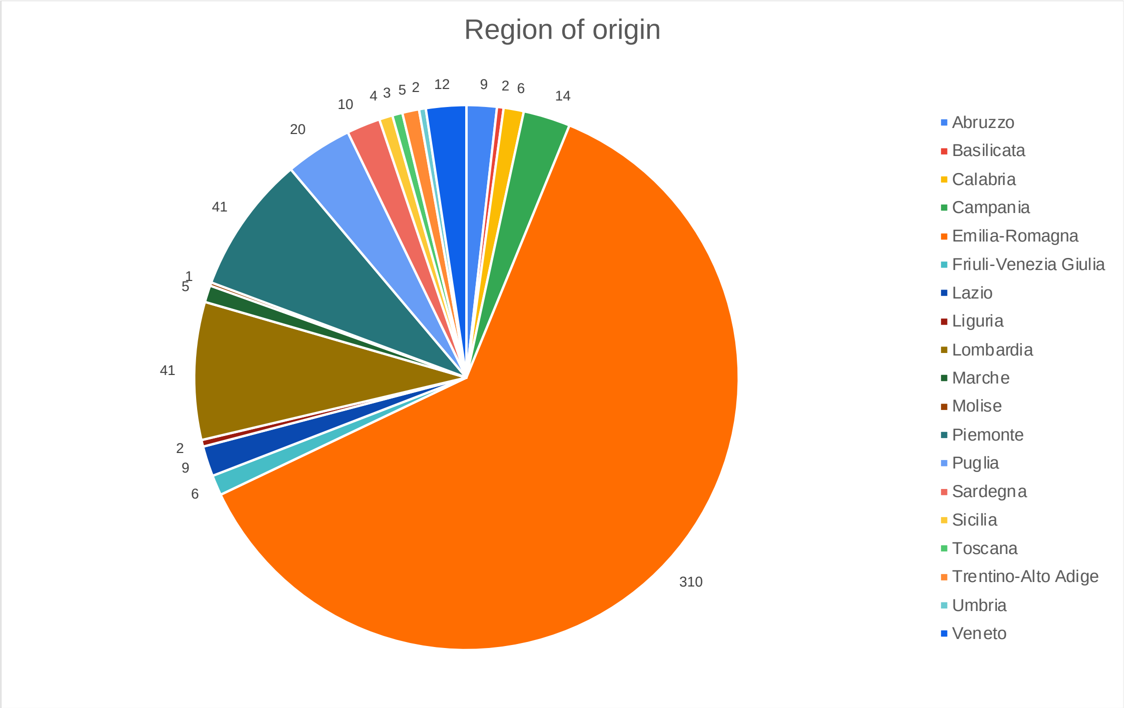

Fig. 6. Region of origin of the participants. Most of the compilers come from Emilia-Romagna.

## Traceability-related questions

After the previous 4 questions, the survey proceeded with the questions that are specifically related to the consumers' preferences.

The first question is "How important to know the origin of the food you eat?" (Fig. 7). The main objective of this question is to understand if the consumers are interested in knowing the origin of the food that they buy and eat. Their interest is vital to understand if the adoption of an improved traceability system would also reflect in an increased interest by the consumers, as showing transparency to improve consumers' trust is one of the main goals of the blockchain adoption in the food supply chain (Srivastava and Dashora, 2022; Pearson et al, 2019). The possible answers were "not important", that shows an absence of interest towards the origin of the food, "quite important", that means it is a minor element for the choice, and "very important" and "crucially important" that are meant to assess how strong is the interest of the respondant consumers if the known origin is an important element when they purchase food.

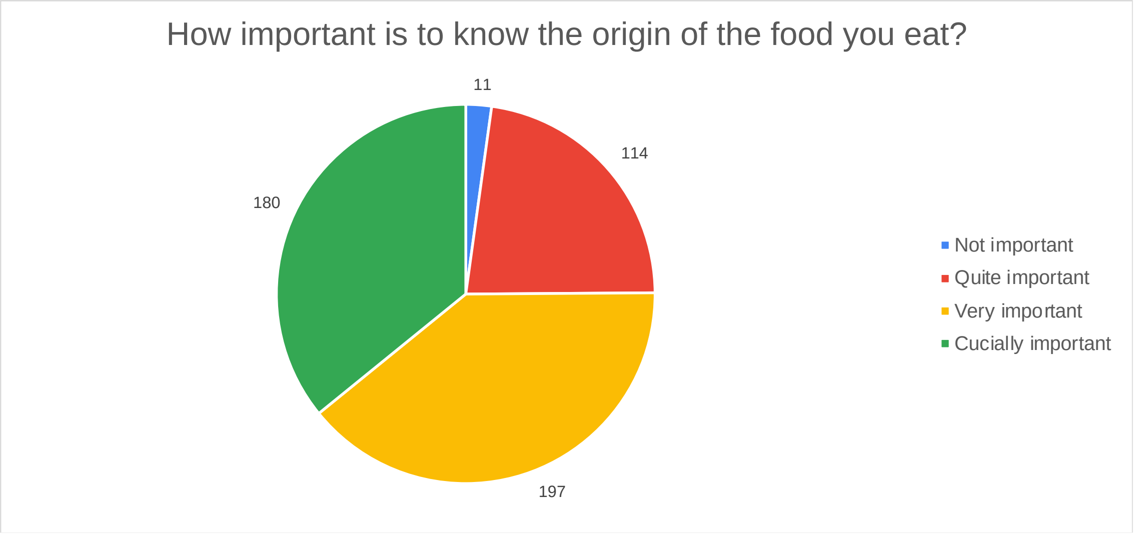

Fig. 7. Number of answers of the first question: "How important to know the origin of the food you eat?".

Consumers appear highly interested in knowing the origin of the food: the vast majority declared that it is a very important or a crucially important parameter when they buy food, accounting for 39.7% and 35.9%. During the live interviews, some of the most interested respondents also added that if a food is made in Italy is usually preferable for them. 114 respondents declared that it is quite important and only 11 respondents declared that the origin is not important at all, accounting for 22.7% and 2.2% on the total. When asked the reason of their response, some people that declared that the origin is not important or is quite important answered that is a matter of how it is made and the safety that the food has instead of where it has been produced or a matter of price (as economical food is always their choice).

This may also be a consequence of the pandemic, as consumers' interest is shifted toward local food (Eger et al., 2021), thus the indication of the origin has become an important parameter for purchase decision.

To understand if the age has any role in the purchase preferences, the answers has been compared to the age of the respondents (Fig. 8). Interestingly, the Over 50 YO show an high interest towards the origin of the food: only 2.3% declared an absence of interest and the 13.1% declared that is quite important. The distribution is shifted toward the "very important" for the 26-35 YO and 35-50 YO, where respectively the 40.7% and the 48.2% of the respondents put their preference. The 18-25 YO showed a different trend as well, preferring the "quite important" option for their choices for the 46.9%. This reveals that the origin is a considerable element in the choice of what food to buy for the elder people, less for the younger generations. This trend may be partially due to the fact that the 18-25 YO usually still living with their parents, and they may put less attention on the food purchases.

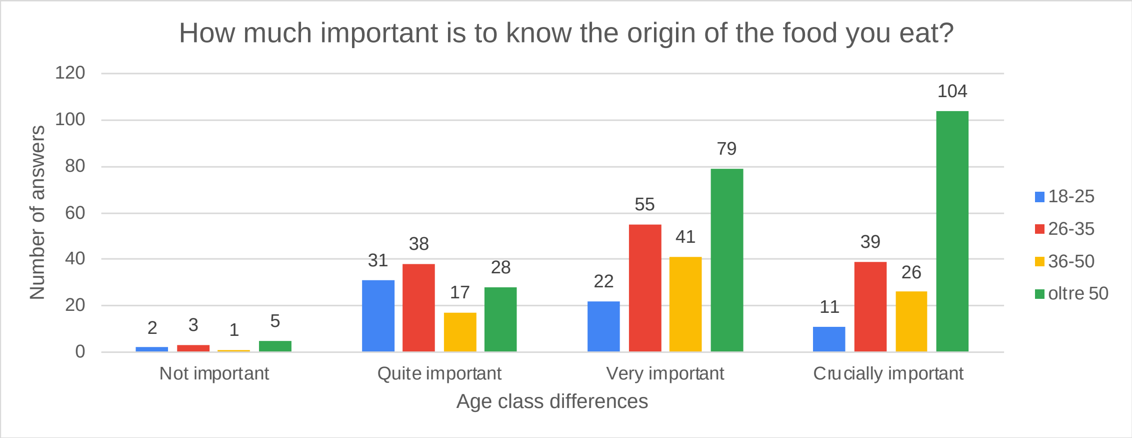

Fig. 8. Age class distinction for the first question. The Over 50 class sees the origin as a crucial parameter that can orientate the purchase, whereas it is less important in younger age classes, particularly the 18-25 YO.

The second question is “Do you control the origin of the food when you buy it?” (Fig. 9). If the first question was related to a general preference toward the origin, the second is much more practical and it refers to the act of checking if the origin is declared and where it comes from during the shopping for food. This is meant to understand if any link that leads to a blockchain traceability may be interesting and engaging for the customers. A project like Bytable’s Trace My Eggs collected a slightly scarce interest of 21.1% single access to the traceability webapp in the USA (Bumblauskas et al., 2020) and the idea is to assess if a similar system would have a similar impact.

The answers reveal that the majority check for the origin of the food, as 39.8% of the respondents is use to check often where does the food they buy comes from and the 35.9% always does it. The 24.1% check the origin only sometimes and when personally asked some compilers answer that their tendency to control the origin also depends by the kind of food (as shown in one of the further questions). Only the 3.8% does not check for the origin of the food: also in this case it depends by the safety and the affordability of the food regardless of the origin.

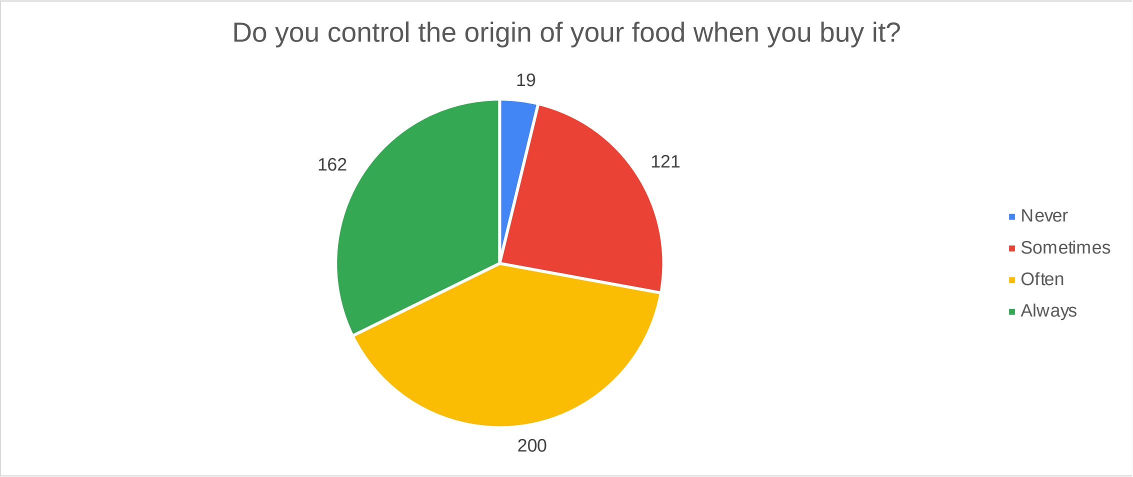

Fig. 9. Number of answers of the second question: “Do you control the origin of the food when you buy it?”

When compared with the age of the respondents (Fig. 10), the trends are similar to the previous question. Not surprisingly, the Over 50 YO class is more interested in the origin and it is more incline to check it at the moment of the food purchase, whereas 26-35 YO and 36-50 YO check it more “often” than “always” and the 18-25 does it only occasionally.

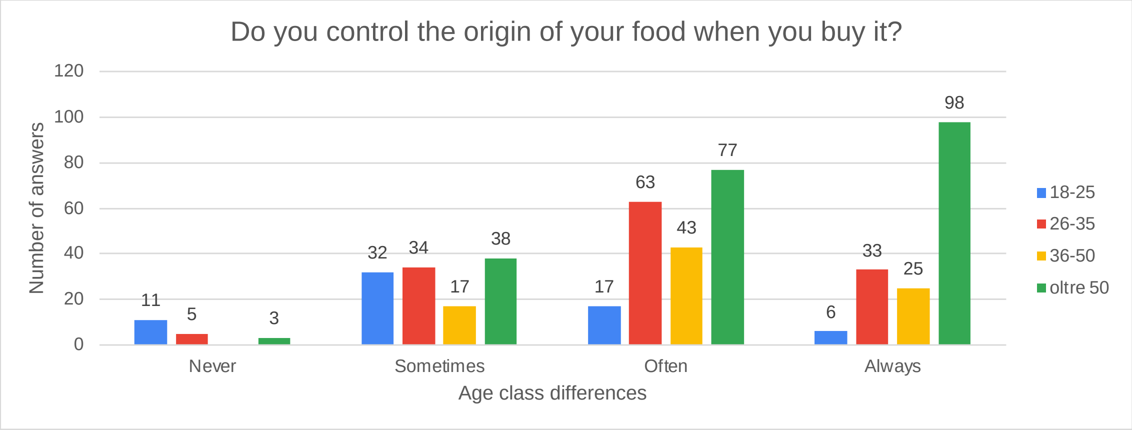

Fig. 10. Comparison between age and origin check of the food.

The third question is “where do you usually shop for food?” (Fig. 11). The place for food shopping has been only considered in physical version as the questionnaire has been prepared prior to the pandemic, then the lockdown measures to prevent Covid19 spreading which changed the shopping habit. Consumers generally changed their attitude, tend to limit their buying to essential things, to buy local (which may have increased the “local market” and “directly from the producers” options) and to embrace e-commerce (Accenture, 2020). If this change will be permanent, it is yet to be seen, as at the moment of this research is being written we are still in the pandemic.

Multiple answers were accepted for this question, but the trend is clearly shifted toward the supermarket. 426 people out of 502 (84.9%) shop at the supermarket and 264 shop *only* at the supermarket, which is the 52.6% of the total: this shows a strong preference toward the large-scale retailers and, by personal communication, some compilers stated that their preference is for practical reasons as any food that they can look for is found in the big supermarket, thus shopping at those retailers saves them time.

The comparison with the age (Fig. 12) show that there are no relevant differences and the trend is clearly towards the supermarket for all the age classes.

It is safe to assume that almost all the participants shop at the supermarket, regardless of the age.

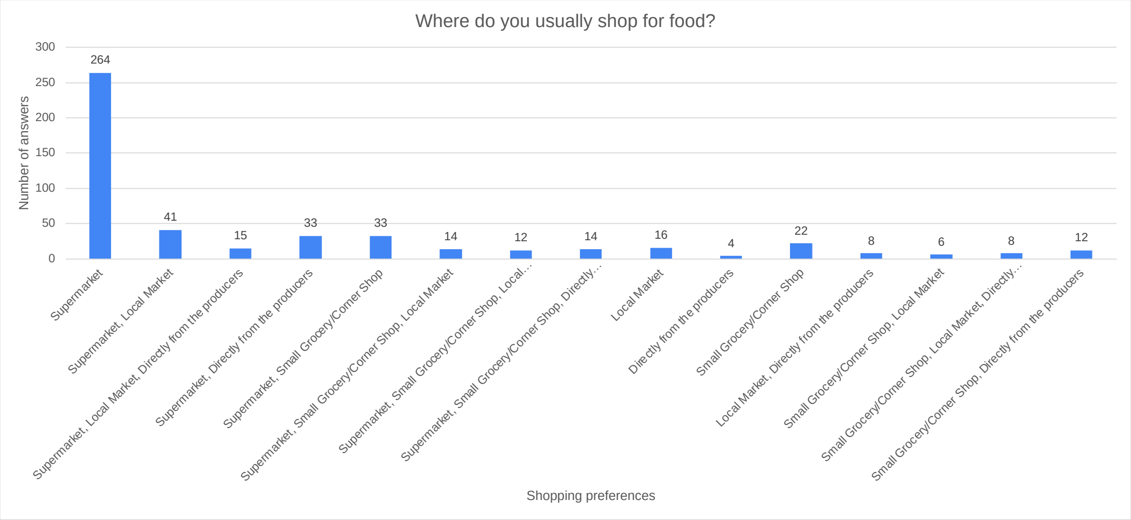

Fig. 11. Number of answers of the fourth question: “Where do you usually shop for food?”. The answers are counted “cumulatively”, namely if a person selected both supermarket and local market that is visualized as a single respondent that use to shop at those two options.

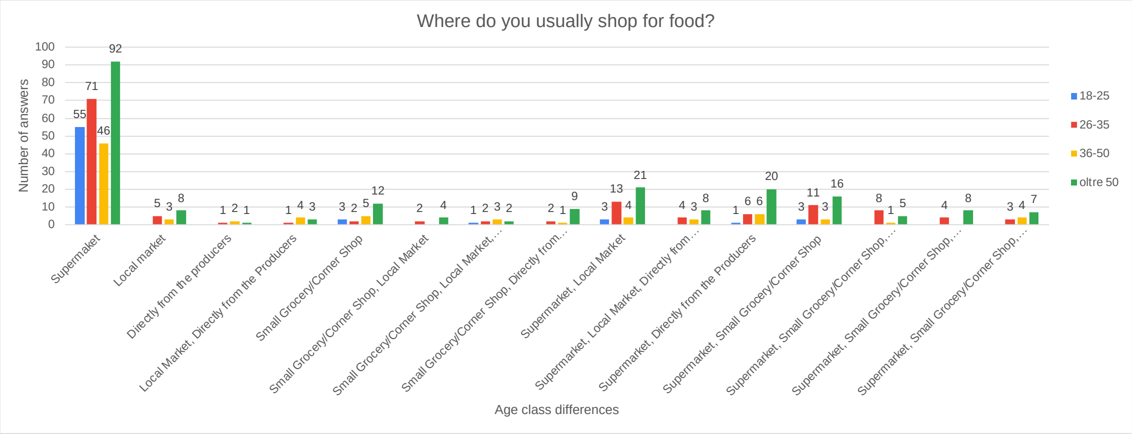

Fig. 12. Comparison between age and food shopping place preferences. Same as Fig. 11, the answers are counted "cumulatively" and divided for age classes.

The fifth question is "Do you consider yourself informed about the food traceability?" (Fig. 13). This question has been posed to understand the general information and personal consideration of the knowledge possessed by the respondents regard the traceability systems and the regulations applicable to trace the food. 50.6% of the respondents declared that they are only "quite informed", which means that they have only basic knowledge of the concept of traceability but nothing further and 33% declared to possess no knowledge on traceability. This question can also be an indicator for a further need of a better communication of the traceability systems, as the EU has a complete and useful framework that consider most of the food products that are available in the market, both animal and plant origin and both within or externally from the EU itself (EU commission, 2007).

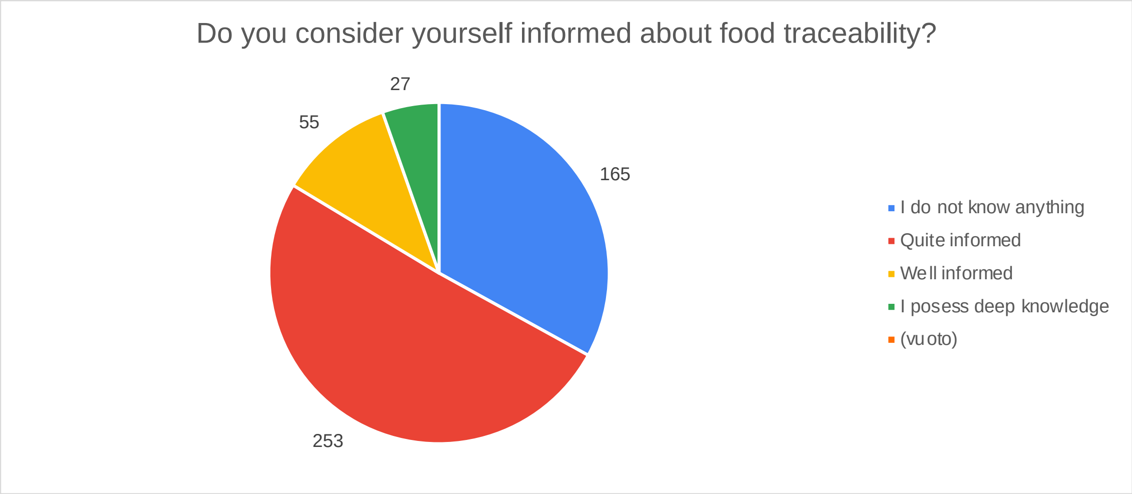

Fig. 13. Number of answers of the fifth question: “Do you consider yourself informed about the food traceability?”.

By comparing the answer with the age (Fig. 14), the 18-25 age class is the one that appears to be less informed about the food traceability, whereas the other classes declared a slightly more consistent knowledge.

A discussion must be done over the possible Dunning-Kruger effect, a cognitive bias that affects people with scarce knowledge on a subject to give themselves an overly positive assessment of the knowledge that they believe they possess: this may affect all the participants regardless of the age classes and the instruction level and it may shift the personal evaluation to an higher level (Kruger and Dunning, 1999; Schlösser et al., 2013). However, the vast majority of the compilers answered “I do not know anything” and “quite informed”, which are the lowest level of knowledge. Even if there is a bias, it does not affect the tendency of this answer.

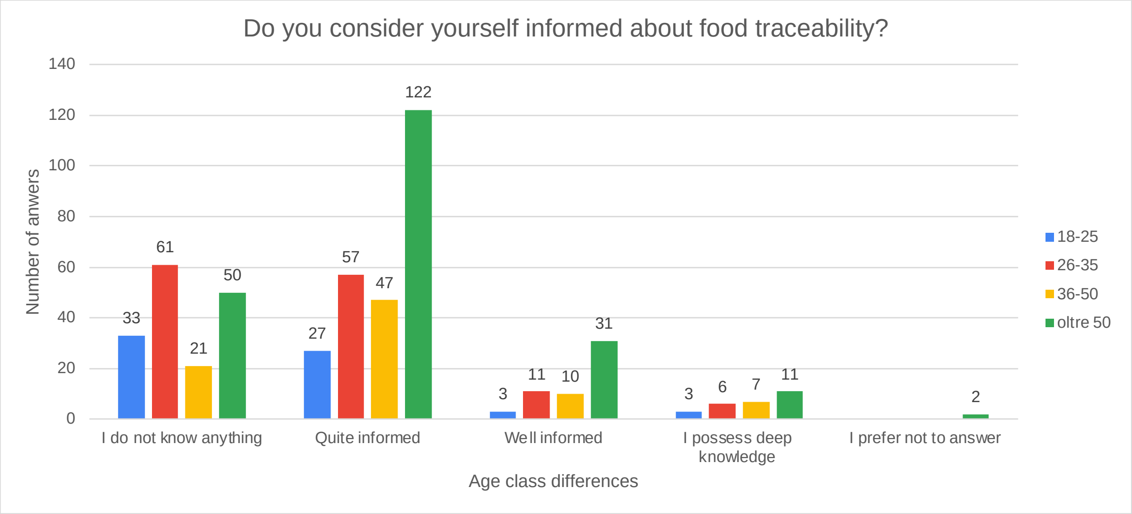

Fig. 14. Comparison between age and personal knowledge on traceability. The 18-25 YO class consider themselves less informed than the other categories.

By comparing the previous answers with the instruction level (Fig. 15), it is shown that the personal knowledge on food traceability does not depend by the instruction level itself. This may depend on the kind of study that the respondents have done, as an engineer or a physicist have obviously a different knowledge than a biologist or an agronomist, which instead may have this subject included in their degree programme.

Food traceability is a subject on everyone should have at least basic knowledge as food is part of our everyday life: this lack of knowledge may derive from a lack of communication by the bodies responsible for food traceability and communication, thus this can be considered an indication for further studies and institutional communication program.

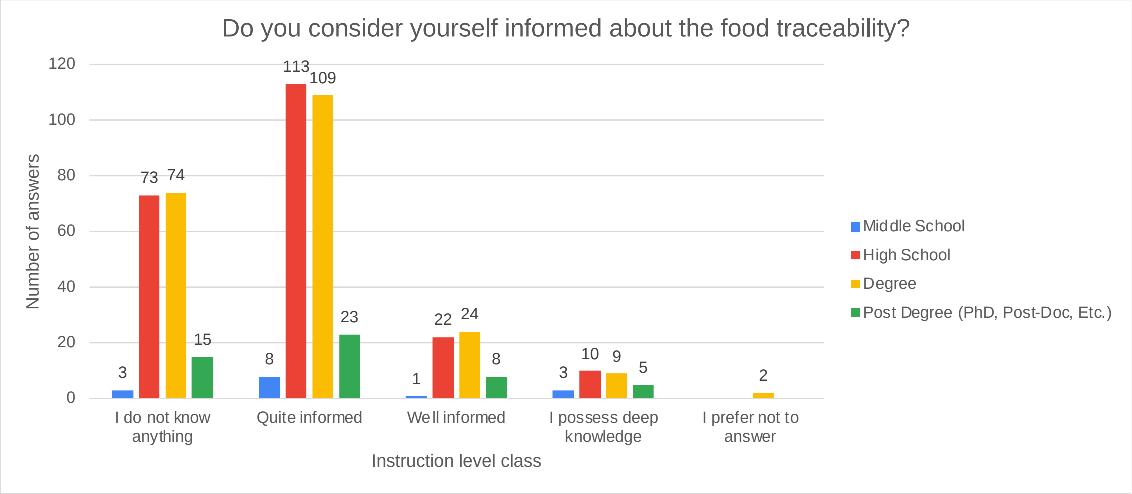

Fig. 15. Comparison between age and personal knowledge on traceability. The trend of the answer is comparable with the age class comparison.

The sixth question is "With the modern digital traceability systems, the consumers may actively verify the origin of the raw ingredients. Having easy-to-use instruments would increase your interest toward traceability?" (Fig. 16). Its meaning is to assess if an active engagement in the traceability control would increase the interest of the respondents towards traceability and if it would be involving to proactively access to a digital system to gather more knowledge on the story of the food that they are buying. The majority of the respondents declared that is would be "definitely" and "a lot" more interested in the traceability, accounting for 43.2% and 29.9% of the total. As for the previous question, this can be an indicator for the communication, as a call to action may be a driver for consumer involvement and an encouragement for their interest in the digital world (Morgan-Thomas, et al., 2020).

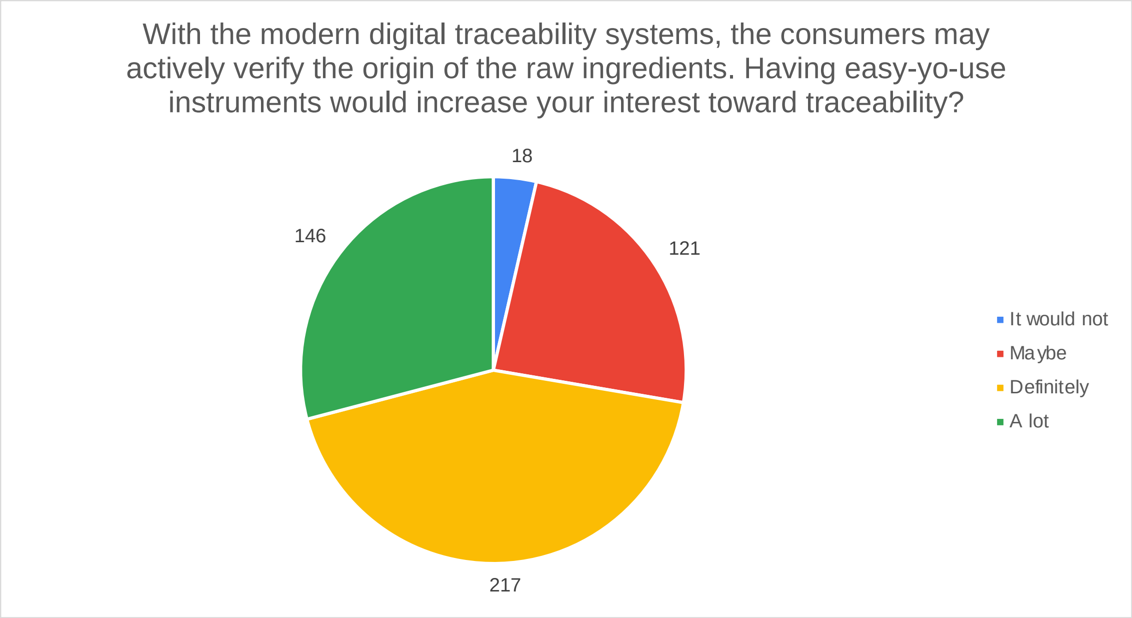

Fig. 16. Number of answers of the sixth question: “With the modern digital traceability systems, the consumers may actively verify the origin of the raw ingredients. Having easy-to-use instruments would increase your interest toward traceability?”

The comparison of the answers with the age classes reveals a possible increase in the interest for all the classes. However, the 18-25 YO seems to be the less interested: a possible reason may be the consistent use of the technology for every activity, less consistent in older people, which may also be translated in a less engaging activity.

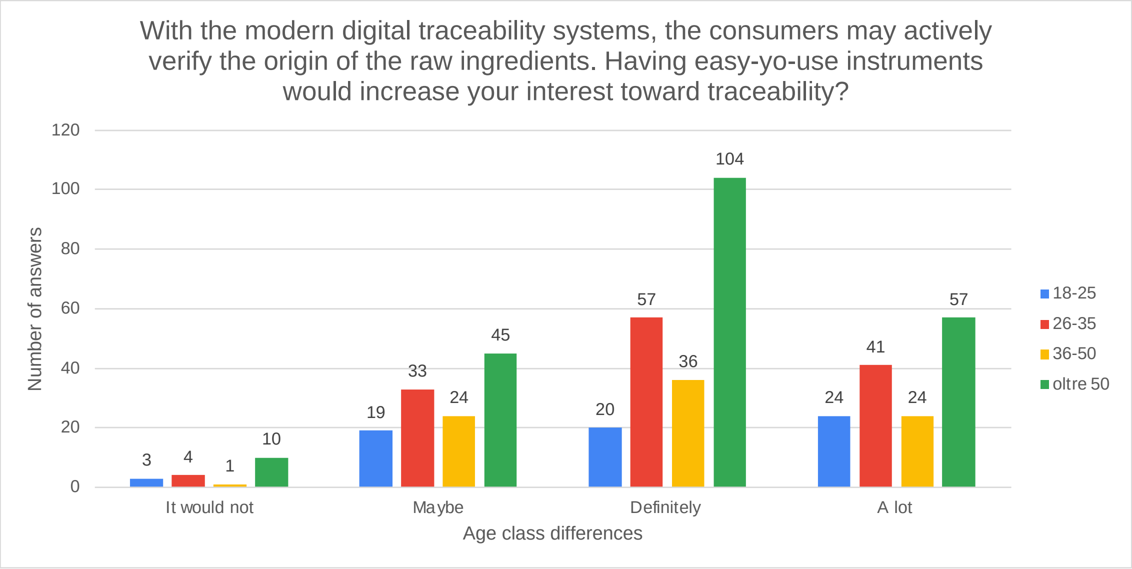

Fig. 17. Comparison between age and increased interest for a digitally traced product. The trend reveals a possible increased interest for all the age classes.

The seventh and eight questions are focused on the preference towards a product provided with digital traceability systems. This first one, “Would you rather buy a product provided with digital traceability, to verify its origin, rather than an unprovided competitor with the same quality?” (Fig. 18) is tailored to assess if the consumers would prefer to buy a specific product (e.g. spaghetti pasta) provided with digital traceability instead of the same product of the same quality but unprovided of digital traceability. The vast majority declared to be likely (51.4%) and absolutely (33.9%) more interested in products provided with digital traceability instead of unprovided competitors.

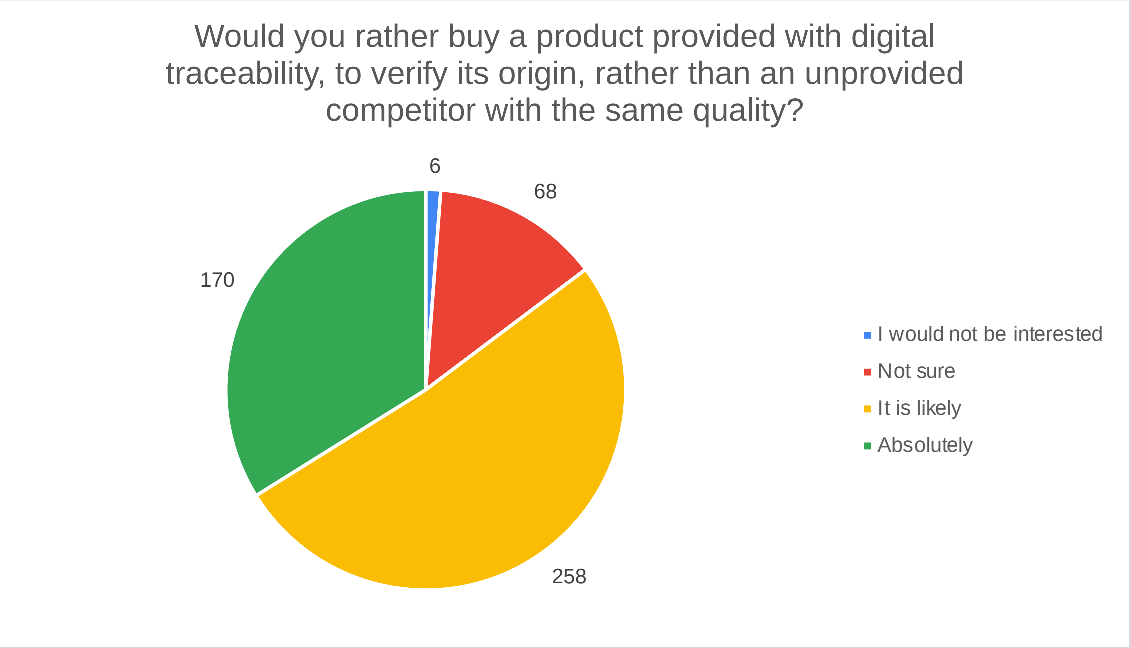

Fig. 18. Number of answers of the seventh question: "Would you rather buy a product provided with digital traceability, to verify its origin, rather than an unprovided competitor with the same quality?"

In this case, the trend is the same for all the age classes (Fig. 19), as the four of them answered mostly that "it is likely" and "absolutely" to be more interested in buying digitally traced product instead of unprovided competitors

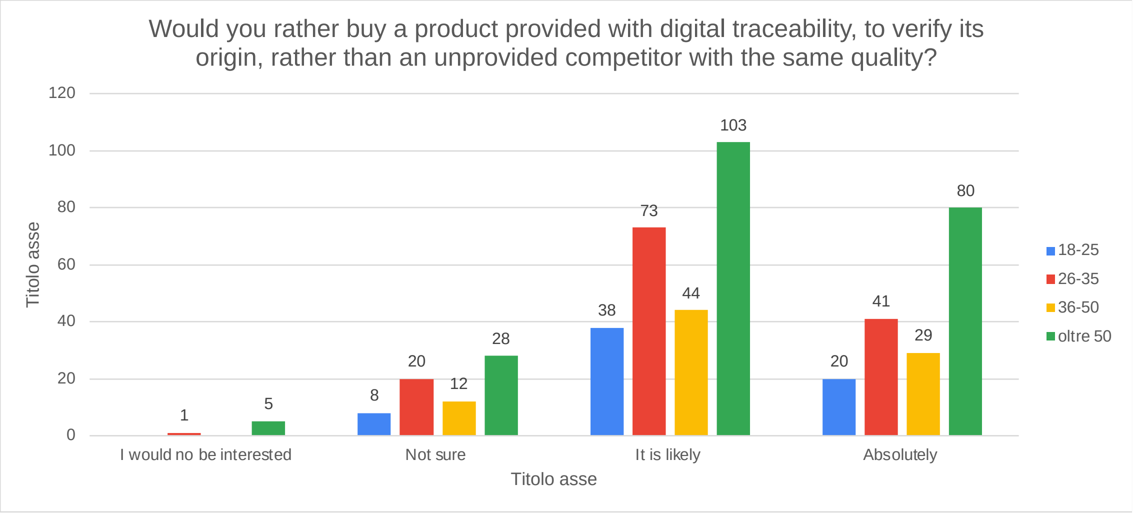

Fig. 19. Comparison between age and willingness to buy digitally traced products instead of unprovided competitors

The eight question is “At the grocery stores the origin of a growing number of food products can be verified by means of digital traceability. Would you rather buy these products instead of unprovided one?” (Fig. 20). The difference with the other is that the comparison is between a digitally traced product and all the other ones, regardless of the kind of food. This is meant to assess if digital traceability would shift the preference to a specific kind of food instead of another (e.g. if a consumer would prefer to buy digitally traced spaghetti instead of unprovided maccheroni or unprovided rice).

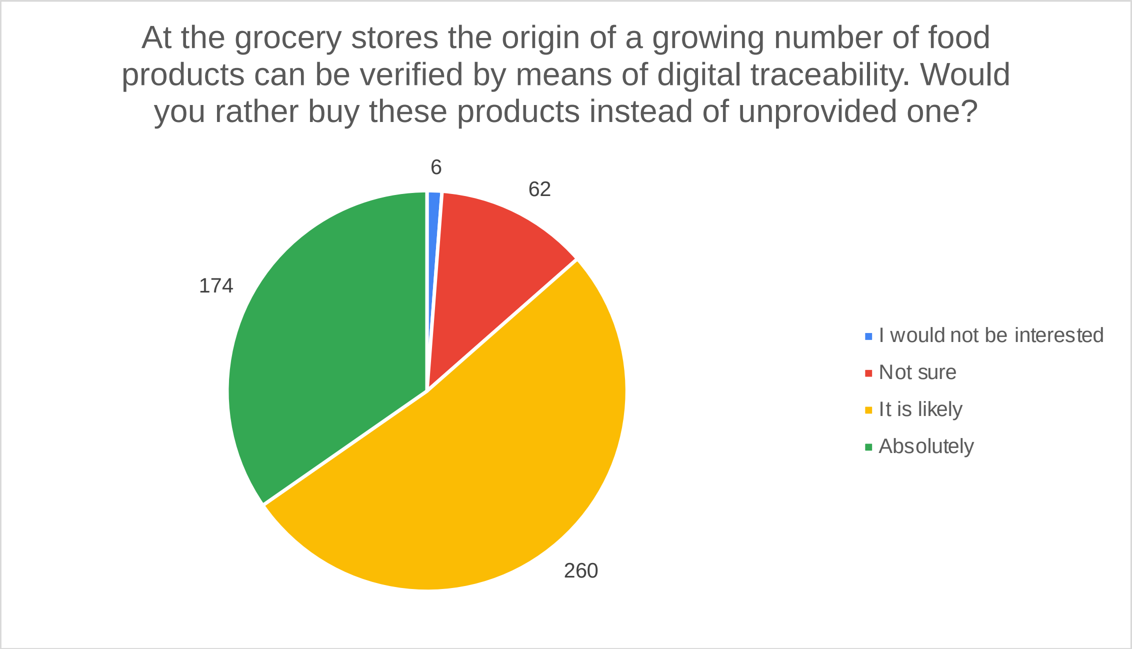

Fig. 20. Number of answers of the eight question: “At the grocery stores the origin of a growing number of food products can be verified by means of digital traceability. Would you rather buy these products instead of unprovided one?”

Similar to the seventh question, the trend is almost identical, and all the age classes declared to be interested in digitally traced products (Fig 21) instead of unprovided ones. These two questions appear to be similar, but the asked respondents declared to have understood the difference between these two questions.

Fig. 21. Comparison between age and willingness to buy digitally traced products instead of unprovided products of a different kind.

For the nineth question, the respondents were asked for products that, in their opinion, require improved traceability (Fig. 22). This question accepted more than one answer as a consumer may would like to see more than one category provided with improved traceability. the suggested answers were meat, fish, milk and dairy products, legumes, fluor and wheat derived products (such as bread, pasta, cookies and crackers), chocolate, coffee and tea, seasonal fruit and vegetables, exotic fruit and vegetables, oil and other condiments, but there was also the possibility to add other options.

This question has value for the consumers: their opinion on the need of a better and clearer traceability system may influence the producers to adopt blockchain technology or other digital traceability systems, as producers are pushed to adopt strategies to match the consumers’ requests (Guptil et al., 2018). It has a value for the producers, that can decide to implement digital traceability systems for their supply chains to distinguish themselves from the others. It also has a value for the regulators, as the consumers have a power of choice that can influence politics and economics, thus an appropriate regulation on the digital traceability may become important following the consumers demand (Torjusen et al, 2001; Holzer, 2006).

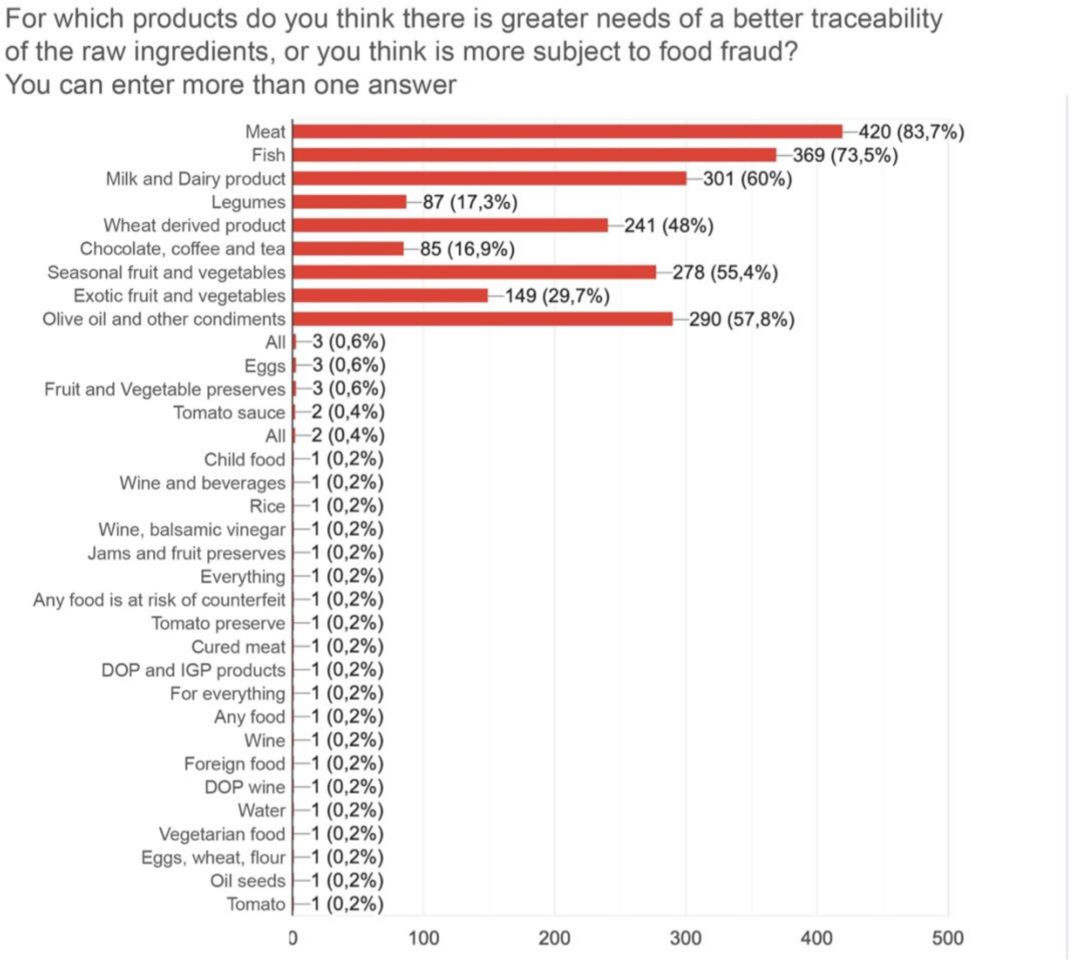

Fig. 22. Number of answers for the nineth question: “For which products do you think there is greater needs of a better traceability of the raw ingredients, or you think is more subject to food fraud? You can enter more than one answer”. The answers are visualized as single answer for each category and as there was the option to enter more than one, the total appears to be more than 502.

Meat is the first single category that, in the opinion of the consumers (83.7% of the single choices), require an improved traceability, not surprisingly it is a category on which several papers have been focused on (Lin et al., 2020; Sander et al., 2018; Cancer Zain, et al., 2018; Aboah and Lees, 2020). It also has a considerable economic value, thus the consumers may have been driven to this option also because it is among the most expensive food categories. A similar deduction may be applied for the fish, which is the second most voted category (73.5% of the single choices) and, similar to the meat, several theoretical and practical studies have been done on the traceability of this food category (Hang et al., 2020). The third category is the milk and dairy product, which also includes yogurt, cheese and other products (60% of the choices). It is interesting to note how the first three most voted category are from animal origin and only the fourth, which is Olive Oil and other condiments, is plant-based. This possibly reveals that the consumers are more concerned about animal-based food than the plant-based one.

Regarding the single cumulative choices (Fig. 23), most of the respondents voted for all the suggested categories, 28 over 502. The following 8 most voted cumulative options included meat and most of them included fish as well. The respondents that did not voted for fish and meat did not vote for any animal-based product, indicating that their diet may be vegetarian or vegan. 6 respondents added “All the foods” (in any grammatical variant): when personally asked, two of them answered that in their opinion there is a general need of an improved traceability for any kind of food as there still being too many frauds.

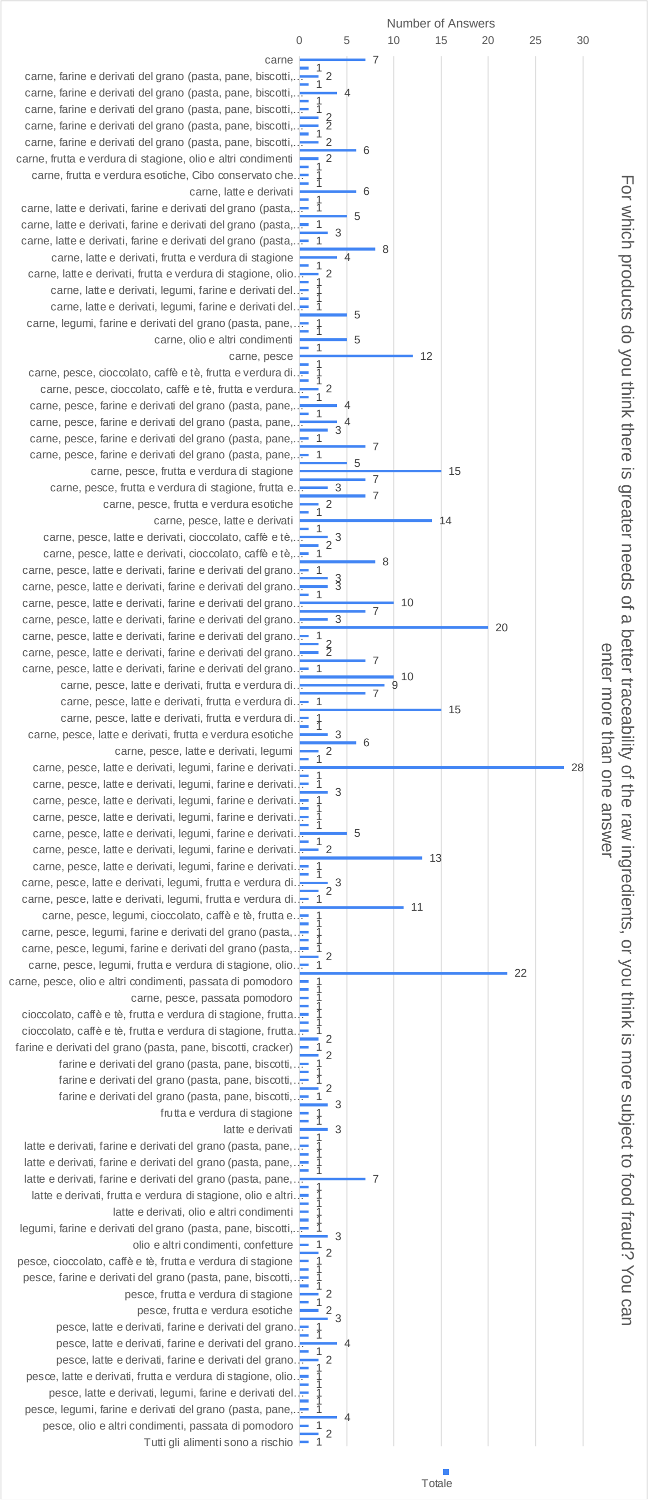

Fig. 23. Cumulative answers to the nineth question. Most of the respondents indicated meat and fish, the ones who did not may be vegetarian or vegan.

The tenth question is “Which aspect/s is/are more important when you buy food?”. Same as before, this question accepts multiple answers, accepts suggestions and some options were given: certified origin of the raw ingredients, low price, organic, protected designation of origin (PDO) or similar (DOC, DOP, DOCG), few chemical additives. 59% of the customers voted for the certified origin of the raw ingredients (296 single votes), 50.2% (252 single votes) voted for few chemical additives, 36.1% (181 single votes) voted for PDO products, 27.3% (137 single votes) voted for organic and 18.9% (95) voted for low price.

The cumulative answers (Fig. 24) show that most of the interviewed consumers find the certified origin and the few chemical additives crucial aspects when they buy food. Traditionally, aspect like lower food prices, attributes of convenience, health, pleasure and elements associated with responsible consumes, such as animal welfare-friendliness and environmental sustainability have been important to consumers in their food choices (Hughes, 2009). However, the pandemic has also been an important drive for attitude shift in consumer choices and now a guaranteed origin for the food has become a crucial aspect (Eger et al., 2021) and this may a reason for the consumer interest towards the certain origin option.

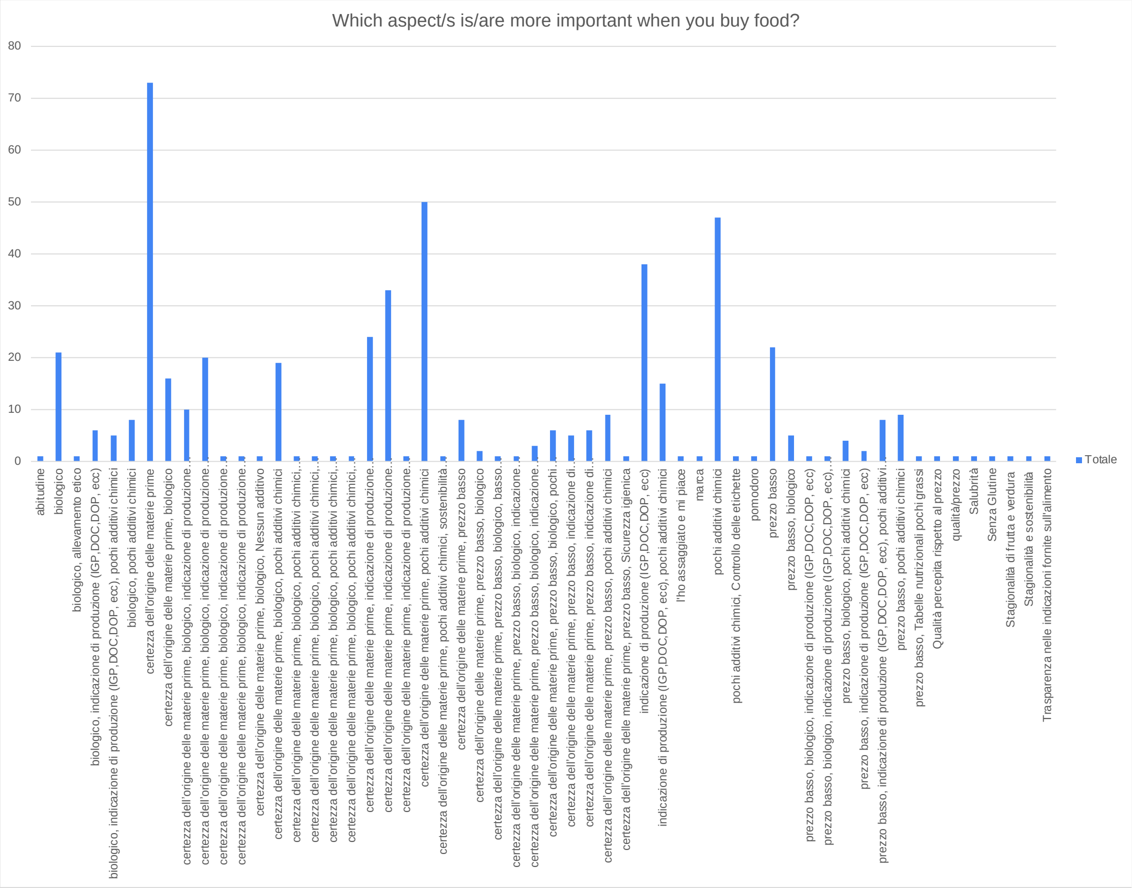

Fig. 24. Cumulative answer of the tenth question: “Which aspect/s is/are more important when you buy food?”. Certified origin of the raw ingredients and few chemical additives are the two most voted options.

The eleventh question is “have you ever heard about blockchain?”. This question is posed to understand if and how many respondents have any knowledge towards blockchain, a buzzword that is usually linked with cryptocurrencies and NFT (Non Fungible Token). 46% of the respondents have never heard about it and the 31.9% have only heard the name (so basically they only know about the existence of the blockchain, but nothing more), which indicates a general lack of knowledge about this technology. Only the 17.5% declared to have knowledge and information on this subject and the 4.6% possess a consistent knowledge about how blockchain works and how it is applied on the different subject.

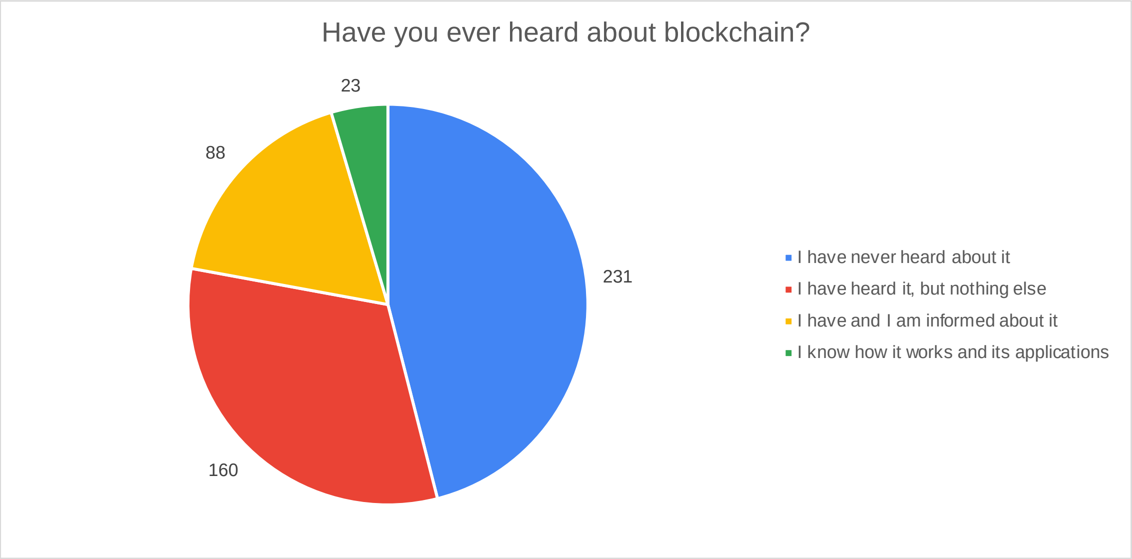

Fig. 25. Number of answers of the eleventh question: “have you ever heard about blockchain?”.

The comparison with the age class (Fig. 26) reveals a decreasing trend for the Over 50, a class in which the most of the participants have zero or a little knowledge about blockchain, whereas the distribution of the others reveals a decreasing trend as the majority of the respondents have a lack of knowledge but a more consistent part of them have some knowledge on this subject.

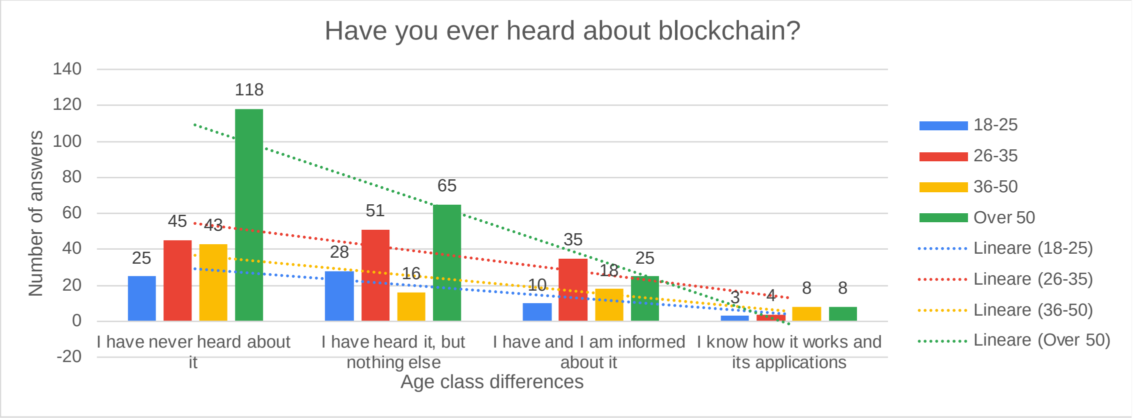

Fig. 26. Comparison between age class and knowledge about blockchain. The Over 50 class is the one that most decreasing, whereas the others are less steep, meaning that in this case there is a difference in the knowledge

An interesting comparison is the one with the self-evaluated knowledge on the blockchain and the instruction level. In this case, the participants that possess a Post Degree title have a little more knowledge compared to the other classes. This implies a possible gap between this class and the others due to the novelty of this technology: it is true that Satoshi Nakamoto wrote the Bitcoin white paper 13 years ago, but the technology remained unknown for years to the masses and only after the popularity explosion of the cryptocurrencies it has been common to hear about the blockchain. Some compilers assessed that they know something about cryptos, but they did not know the name of the technology behind them.

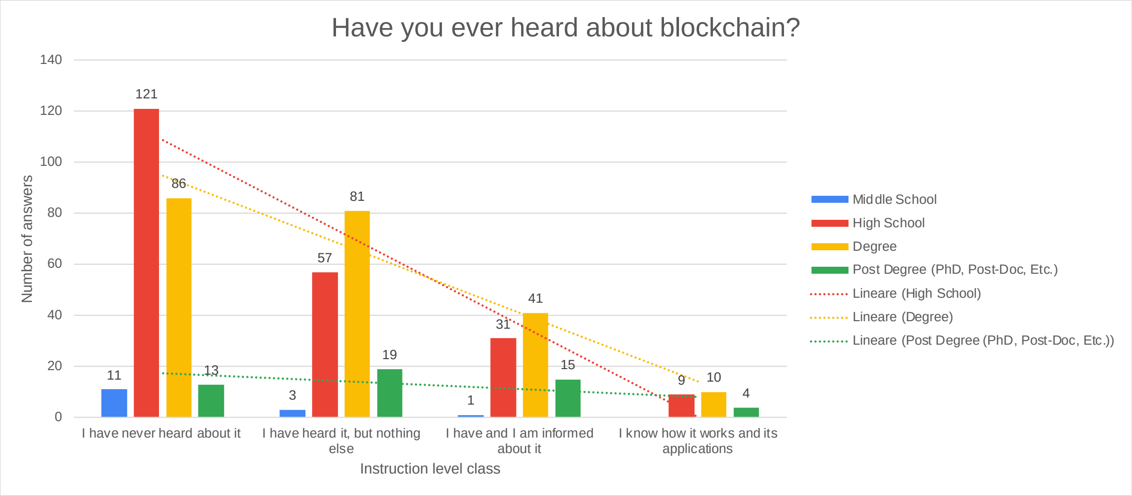

Fig. 27. Comparison between instruction level and knowledge about blockchain. The participants that possess a Post-Degree instruction level have a more consistent knowledge about the blockchain

The last of the question, the twelfth, is “How much more would you spend for a guaranteed traceability?”. This is one of the most important question, as it reveals the real interest towards digital traceability. the vast majority of the participants declared that they are willing to spend up to 5% increase on the original price for the 37.5% and up to 10% for the 31.5% and the 10.6% is willing to spend up to 20%. Only 14.5% of the respondents do not want to spend more for an improved traceability as they declared that it should be mandatory to show more information regarding the food traceability.

Violino et al. (2019) conducted a study on the willingness of the customers to spend more for a digitally traced extra virgin olive oil and they found that their respondents were willing to spend on average 17.8%: this result is higher compared to the one obtained in this questionnaire.

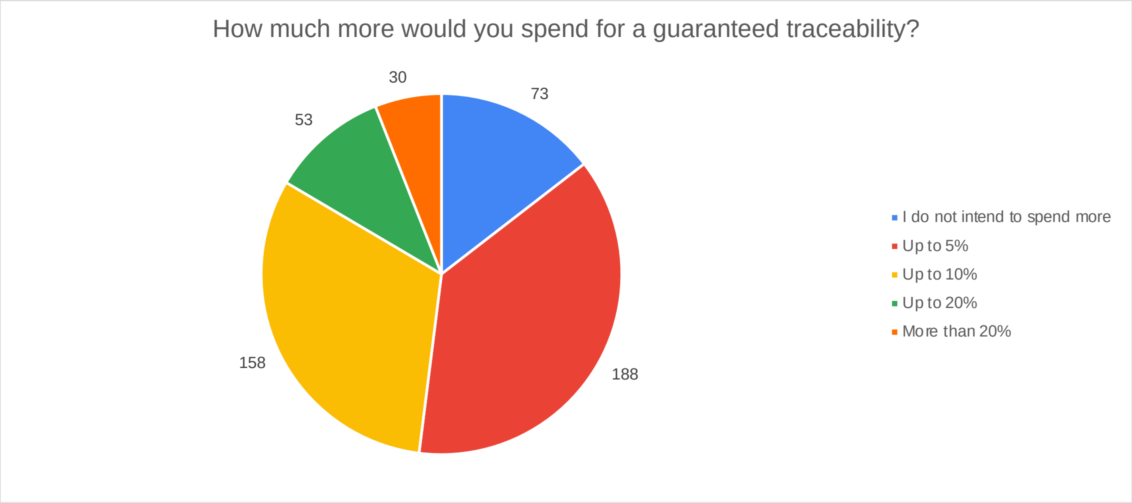

Fig. 28. Number of answers of the twelfth question: “How much more would you spend for a guaranteed traceability?”.

The trend is similar for all the age classes, as the majority of the respondents are willing to pay up to 5% - 10% more for a digitally traced product regardless of their age (Fig. 29). However, the younger 18-25 YO show a slightly greater peak on the 10% instead of the 5% like the other classes: this is interesting as in the previous questions regarding the traceability they appeared to be less interested. A possible explanation may be the prize-winning mechanism and gamification engagement (Fitz-Walter et al., 2011) that is also applicable to the mechanism of the digital traceability (scan the QR to gather more information) that younger generation may be able to imagine and predict more that the older, thus it would be more appealing.

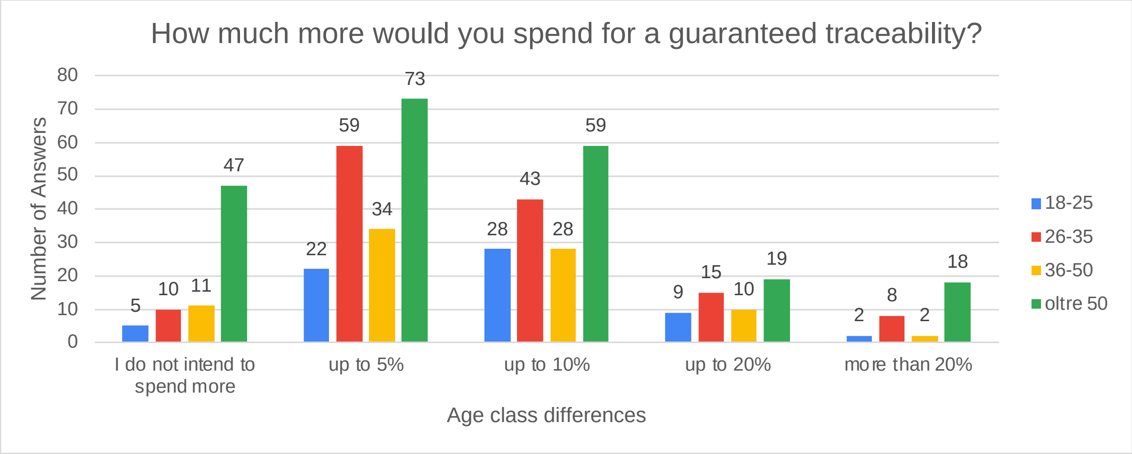

Fig. 29. Comparison between age class and willingness to spend more for digitally traced products. The trend reveals the most of the respondents accept a 5%-10% cost increase for a food product provided with digital traceability.

## Discussion

This questionnaire has been prepared in 2018 and it has not been tailored to evaluate any change due to the Covid-19 pandemic, but it certainly had an influence as in different aspects consumers changed their habits in where and what to buy. The pandemic changed the way in which people decide what to buy, making them more aware of quality and purpose when they make a purchase and more conscious about the origin of what they buy (Eger et al., 2021).

There are no questions about the perception and interest toward the origin of the restaurant food: usually consumers are less interested, and it is not written in the menu (Love et al., 2021) unless it is a peculiar food such as DOP or coming from a region with an high vocation for a particular food (such as Fiorentina from Tuscany). The main drivers for the customers in the selection of a restaurant are generally the tastiness and the quality of the food preparations and the consumers' demand for fresher and higher quality food products. However, the need of identification trends for environmental movement and growing popularity of locally produced fruit and vegetables provided by local farmers and agribusinesses are interesting factors that may push for the adoption of an improved traceability in the restaurants (Jung et al., 2015), or, at least, it may become a strategic adoption to distinguish the restaurants that serve local products.

The result of the first two question about the origin of the food is interesting as younger generations are aware of the many problems concerning the food supply chain and its impact, possibly even more that their parents. They tend to buy and consume organic food rather than traditionally made one more than the older generations (Azzurra et al., 2019), and, by the moment that organic food is usually associated with "local" and "0 Km" (Jensen et al., 2019), the 18-25 YO and the 26-35 YO were expected to be more interested than the Over 50 YO in the origin of the food. A same result comes from the third question, showing that the 18-25 YO are consider themselves less informed about traceability than the older age classes.

Interestingly, slightly before this questionnaire has been designed, Violino et al. (2019) conducted a similar survey on consumer, even though it was specifically focused on the Extra Virgin Olive Oil (EVOO). The four profiling questions are the same as the ones presented in this part, but the other are strictly related to the EVOO, like how many time the respondents consume EVOO per week and how much do they spend for it. However, the questions also included the interest towards the origin of the EVOO and how much would the respondents spend for a bottle that is provided with integrated digital traceability systems. The interviewed consumers are interested in the origin of the EVOO, they would choose blockchain traceability system over the others as the QR scan has a prize-winning mechanism that improve the interest and they declared the willingness to spend up to a 17.8% increased price for a traced bottle of EVOO. These results are comparable with the opinions gathered in the questionnaire previously described, even though Violino et al. (2019) focused on a specific food. Also, Olive Oil is a food that for the 57.8% of the interviewed in this questionnaire require improved traceability. There are examples of blockchain provided EVOO, such as Olio Nece (https://www.olionece.it/blockchain-traceability), but it still being the minority and in the common supermarket such products are not found.

## Limitations

The compilers come mostly from Emilia-Romagna, Lombardia and Piemonte. These 3 regions represent the 61,8%, 8,2% and 8,2% for a 78,2% of the total. This is a bias that is due to the extension of this study, and even if it has been carried out mostly online, the published articles and the social network promotion reached mainly people from the region that include the University of Modena and Reggio Emilia. This limited the possibility to relate answer with the origin and even to relate macro areas such as north and south with consumer preferences.

Another limitation is the age of the participant, which is mostly represented by women over 50 YO. The reasons of this bias may be firstly because the social network groups in which this questionnaire has been shared and promoted are used mainly by people of this age class, but another reason may be the more attention that over 50 YO people put when they buy food.

The media coverage may be improved by writing magazine articles for more consumer journals, as the one that published the questionnaire may have been too restricted to specific sectors and subjects. The establishment for a collaboration with an important consumer journal has been tried, which might have been advantageous as it covers the entire country, but, in the end, it has not been possible to publish the questionnaire due to different editorial choices.

For a future similar study, a solution may be to physically gather consumer opinion via live interview at least in supermarkets and local markets, possibly in different regions as this may also improve geographical coverage and representation, and to find better and useful collaborations to gather a wider consumer sample.

## Conclusions

This questionnaire reveals some important factors. Most of the interviewed consumers are interested in food traceability, they desire an improved traceability for mainly animal products, meat fish and dairy in particular, they would rather buy digitally traced food instead of unprovided competitors and if a product would show improved traceability systems it would be more appealing.  Who think the origin of the food is important is also use to check for it at the moment of purchase and the prize-win gamification would be a driver for the purchase choice for the younger generations.

The most important factor, nonetheless, is the average acceptance of a 5% - 10% cost increase for a digitally traced product. The companies must face project and maintenance costs to provide for an effective digital traceability system, a cost that can easily grow up in function of the complexity of the supply chain and the total volume of transaction. It is also a fact that this cost must be reflected on the customers: if this cost can be maintained below the 10% increase threshold, it can be translated in a win-win for both the customers, that will be more informed, and the companies that can be distinguished from the competitors.

## Bibliography

- Aboah, J., & Lees, N. (2020). Consumers use of quality cues for meat purchase: Research trends and future pathways. *Meat Science*, *166*(April), 108142.
- Accenture, (2020). How COVID-19 will permanently change consumer behavior. Available at [https://www.accenture.com/_acnmedia/PDF-134/Accenture-COVID19-Consumer-Behaviour-Survey-Research-PoV.pdf#zoom=40](https://www.accenture.com/_acnmedia/PDF-134/Accenture-COVID19-Consumer-Behaviour-Survey-Research-PoV.pdf#zoom=40)
- Azzurra, A., Massimiliano, A., & Angela, M. (2019). Measuring sustainable food consumption: A case study on organic food. *Sustainable Production and Consumption*, *17*, 95–107.
- Berneis, M., & Winkler, H. (2021). Value Proposition Assessment of Blockchain Technology for Luxury, Food, and Healthcare Supply Chains. *Logistics*, *5*(4), 85.
- Bumblauskas, D., Mann, A., Dugan, B., & Rittmer, J. (2020). A blockchain use case in food distribution: Do you know where your food has been? In *International Journal of Information Management* (Vol. 52).
- Cancer Zain, J., Tedja Nugraha, G., Didiet, R., Hidayat, R., Budiman, T., & Setiawan, A. (2018). *The Implementation of Halal Supply Chain With Private Blockchain in Indonesia*.
- David Hughes. (2009). European Food Marketing: UnderstandingConsumer Wants – The Starting Point in AddingValue to Basic Food Products. *EuroChoices 8(3)*, 06–13.

- Eger, L., Komárková, L., Egerová, D., & Mičík, M. (2021). The effect of COVID-19 on consumer shopping behaviour: Generational cohort perspective. *Journal of Retailing and Consumer Services, 61*.
- Fitz-Walter, Z., Tjondronegoro, D., & Wyeth, P. (2011). Orientation passport: using gamification to engage university students. In *Proceedings of the 23rd Australian computer-human interaction conference* (pp. 122-125).
- Garaus, M., & Treiblmaier, H. (2021). The influence of blockchain-based food traceability on retailer choice: The mediating role of trust. *Food Control, 129*.
- Guptill, A., Larsen, D., Welsh, R., & Kelly, E. (2018). Do Affluent Urban Consumers Drive Direct Food Sales in the Northeast United States? A Three-part Analysis. *Journal of Agriculture, Food Systems, and Community Development*, 1–14.
- Holzer, B. (2006). Political consumerism between individual choice and collective action: social movements, role mobilization and signalling. In *International Journal of Consumer Studies* (Vol. 30).
- Ismael, D., & Ploeger, A. (2020). Consumers’ emotion attitudes towards organic and conventional food: A comparison study of emotional profiling and self-reported method. *Foods, 9*(1).
- Istat (2022). Laureati in Italia. Available at http://dati.istat.it/Index.aspx?DataSetCode=DCIS_LAUREATI#
- Istat, (2011). Italia in cifre. Available at https://www.istat.it/it/files/2011/03/Italia-in-cifre.pdf

- Istat, (2021). Popolazione residente al 1° gennaio. Available at http://dati.istat.it/Index.aspx?QueryId=18460
- Jensen, J. D., Christensen, T., Denver, S., Ditlevsen, K., Lassen, J., & Teuber, R. (2019). Heterogeneity in consumers' perceptions and demand for local (organic) food products. *Food Quality and Preference*, *73*, 255–265.
- Jung, J. M., Sydnor, S., Lee, S. K., & Almanza, B. (2015). A conflict of choice: How consumers choose where to go for dinner. *International Journal of Hospitality Management*, *45*, 88–98.
- Kruger, J., & Dunning, D. (1999). Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments. *Journal of Personality and Social Psychology*, *77*(6), 1121–1134.
- Lin, W., Ortega, D. L., Ufer, D., Caputo, V., & Awokuse, T. (2020). Blockchain-based traceability and demand for U.S. beef in China. *Applied Economic Perspectives and Policy*.
- Liu, H. (2022). Combating unethical producer behavior: The value of traceability in produce supply chains. *International Journal of Production Economics*, *244*.
- Longo, F., Nicoletti, L., & Padovano, A. (2020). Estimating the Impact of Blockchain Adoption in the Food Processing Industry and Supply Chain. *International Journal of Food Engineering*, *16*(5–6).
- Love, D. C., Turvey, C., Harding, J., Young, R., Ramsing, R., Tlusty, M. F., Fry, J. P., Nguyen, L., Asche, F., Nussbaumer, E. M., Thorne-Lyman, A. L., & Bloem, M. (2021).

Nutrition and origin of US chain restaurant seafood. *American Journal of Clinical Nutrition*, *113*(6), 1546–1555.

- Mainelli, M., & Manson, B. (2016). Chain Reaction: How Blockchain Technology Might Transform Wholesale Insurance. *How Blockchain Technology Might Transform Wholesale Insurance - Long Finance*.
- Morgan-Thomas, A., Dessart, L., & Veloutsou, C. (2020). Digital ecosystem and consumer engagement: A socio-technical perspective. *Journal of Business Research*, *121*, 713–723.
- Moura, T., & Gomes, A. (2017). Blockchain voting & its effects on election transparency & voter confidence. *ACM International Conference Proceeding Series*, *Part F128275*, 574–575.
- Pearson, S., May, D., Leontidis, G., Swainson, M., Brewer, S., Bidaut, L., Frey, J. G., Parr, G., Maull, R., & Zisman, A. (2019). Are Distributed Ledger Technologies the panacea for food traceability? *Global Food Security*, *20*(February), 145–149.
- Rabah, K. (2018). Enhancing Global Innovation Agenda www.thelakeinstitute.org The Lake Institute Convergence of AI, IoT, Big Data and Blockchain: A Review. *The Lake Institute Journal*, *1*(1), 1–18. www.thelakeinstitute.org
- Robertson, J. L., & Barling, J. (2013). Greening organizations through leaders' influence on employees' pro-environmental behaviors. *Journal of Organizational Behavior*, *34*(2), 176–194.

- Sander, F., Semeijn, J., & Mahr, D. (2018). The acceptance of blockchain technology in meat traceability and transparency. *British Food Journal*, *120*(9), 2066–2079.
- Schlösser, T., Dunning, D., Johnson, K. L., & Kruger, J. (2013). How unaware are the unskilled? Empirical tests of the “signal extraction” counterexplanation for the Dunning-Kruger effect in self-evaluation of performance. *Journal of Economic Psychology*, *39*, 85–100.
- Simeone, M., & Scarpato, D. (2021). Consumer Perception and Attitude toward Insects for a Sustainable Diet. *Insects*, *13*(1), 39.
- Singh, A., & Glińska-Neweś, A. (2022). Modeling the public attitude towards organic foods: a big data and text mining approach. *Journal of Big Data*, *9*(1), 2.
- Srivastava, A., & Dashora, K. (2022). Application of blockchain technology for agrifood supply chain management: a systematic literature review on benefits and challenges. *Benchmarking: An International Journal*.
- Torjusen, H., Lieblein, G., Wandel, M., & Francis, C. A. (2001). Food system orientation and quality perception among consumers and producers of organic food in Hedmark County, Norway. *Food Quality and Preference*, 207–216.
- Violino, S., Pallottino, F., Sperandio, G., Figorilli, S., Antonucci, F., Ioannoni, V., Fappiano, D., & Costa, C. (2019). Are the innovative electronic labels for extra virgin olive oil sustainable, traceable, and accepted by consumers? *Foods*, *8*(11).
- Wörner, D., von Bomhard, T., Schreier, Y.-P., & Bilgeri, D. (2016). *THE BITCOIN ECOSYSTEM: DISRUPTION BEYOND FINANCIAL SERVICES?*

## Decision-making flowchart diagram for the right technology to adopt

The choice of the right blockchain technology (BCT) may be difficult as, even if the most successful applications of the blockchain are in the financial and cryptocurrency area, nowadays there are various solution for different applications that providers that offer blockchain services (Berneis and Winkler, 2021). In particular, since the early stage of the development of blockchain technologies, today there are multiple solutions for the application of BCTs to the traceability of the supply chain – whether is in the agrifood sector or not.

In order to identify the best BC technology for each specific use, several scientific papers and other articles have been published as well as other opinions and suggestions by BC providers. Blockchain technology is quite a young one, despite being a buzzword for few years, and the decision might be difficult. Some companies as well published their articles provided with specific tool to help the decision: for example, IBM has an entire section on their website dedicated in helping the decision whether to adopt a blockchain solution. In general, blockchain is an informatic solution that is meant to solve trust-related problems in an environment in which there is a lack of trust: the most important example are the cryptocurrencies. The safety is achieved thanks to the system architecture, that enhance trust data, services and identities (Pearson et al., 2019). The cost of this safety is a heavy and slow system, that implies a particular need for security to justify its deployment, especially in the supply chains.

### Are all the supply chains suitable?

Different supply chains have a different architecture, and some are quite complicated. Our food market is dominated by multinational retailer and big companies that can move huge quantities of food products all around the world, thus the resulting supply chains are multi-suppliers, multi-producers, multi-product (Khalifehzadeh et al, 2015). An example is represented by the useful interactive demo showcased on IBM Food Trust, which once was on blueberry fruit and nut bar and now is about wholegrain Margherita pizza (available on the IBM Food Trust www.ibm.com/blockchain/resources/food-trust/demo/trace), which show how complicated can be tracing back all the ingredients (wheat flour, basil, olive oil, tomato purée, mozzarella, etc.). However, thanks to the scalability and versatility of the blockchain, it is possible to trace each ingredient back to the farm, with the detail decided from each producer. This example shows that the matter is not how complicate is a supply chain, but its structure, which is an intrinsic characteristic of every product.

The supply chains can be divided in two main categories: linear and non-linear (Patelli and Mandrioli, 2020). A linear supply chain is a supply chain in which it is possible to trace at least the main ingredient (or all of them) from the farm to the market shelf. A non-linear one is a supply chain in which the main ingredient is supplied by different producers and their products are mixed together at least in one stage of the supply chain, making impossible to trace the origin of a unit of this product.

An example of the first type, the linear supply chain, can be the pork ham supply chain (Fig 1). The main ingredient is the pork rear leg, that, depending on the kind of ham, it will go through different stage and processing (which may be done in different locations by different actors), but with a pork leg only one ham can be produced. This is valid for other pig meat products that do not involve mixing, even if in some case the structure of the supply chain may be complicated and involve several actors, makers and controllers (Leat and Revoredo-Giha, 2013) and an improved traceability is important to develop resilience and reduce the risk for all the supply chain actors and in every step of the chain.

The second type is represented by the wine supply chain in case of a winemakers cooperative (Fig 2). In this case, the farmers sell the grapes to the cooperative, which mix them together before pressing phase, thus the grape juice lose all its traceability. Even at this point it is impossible to distinguish the product from a specific producer from the others and, after the fermentation and aging (in function of the wine), the only assumption that can be made is that in a bottle there is a variable proportion of transformed grape juice coming from all those farmers (Anastasiadis and Alebaki, 2021). This example can also be extended to other supply chains, such as pasta, rice and many other, which, in a matter of facts, represent the majority of the supply chains.

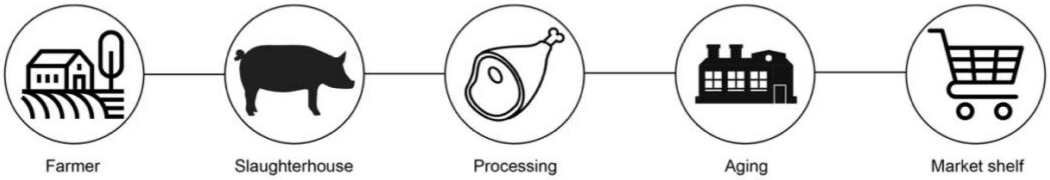

Fig 1. Pork ham supply chain is an example of a linear supply chain. The main ingredient, a pork leg, can be traced linearly from the farm to the market shelf through each production stage.

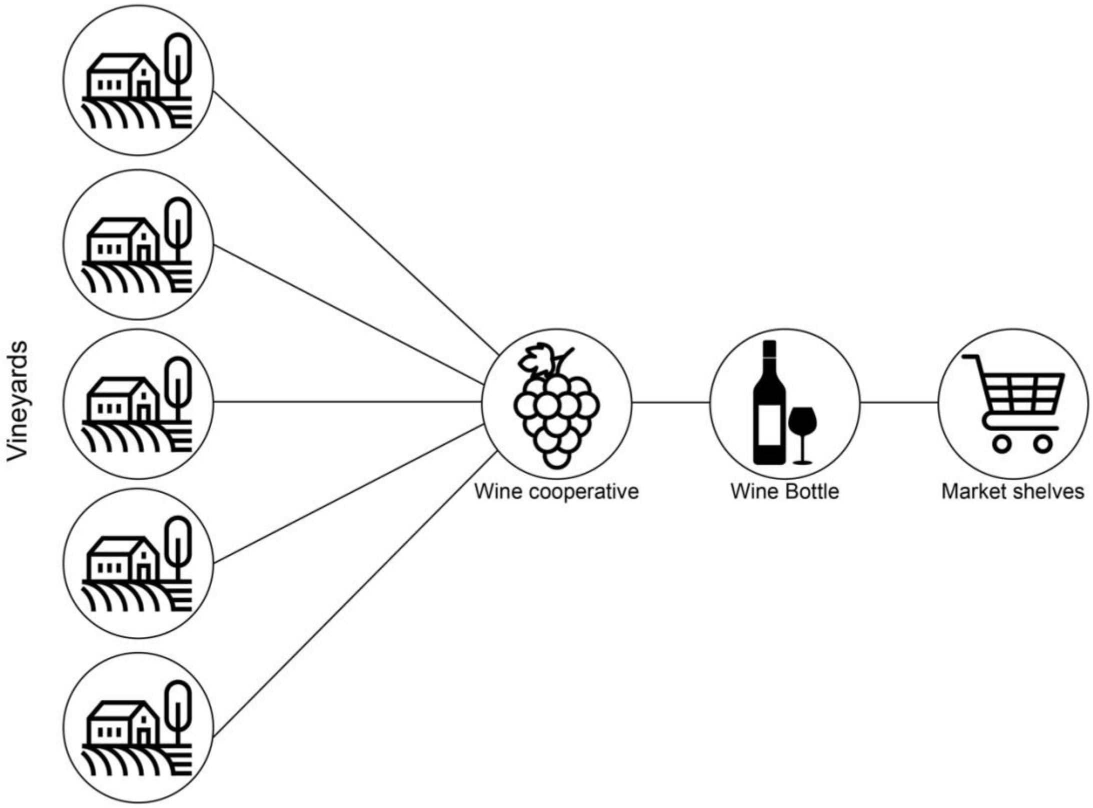

Fig 2. The wine supply chain, for the case of a wine cooperative, is a non-linear one as it is impossible to trace the wine in every bottle as the wine grapes, the main ingredient, goes through at least one stage in which the grapes from all the farmers are mixed. This is a common case in Italy, France and other countries with a strong vocation for wine production.

## Literature analysis and comparison

By researching the relevant scientific literature, several authors dedicated research works on the choice of the right technology that should be applied for each specific case. Four studies have been identified as relevant, as they present a decision-making tree to help to adopt the right technology. These studies have been chosen as the logical algorithms that they present can be easily applied to the food supply chain, even if some of them are more focused on economical transactions and other general purposes that not necessarily take in account the supply chain traceability.

Wüst and Gervais (2017) is the first decision-making tree (Fig. 3) that has been published in a moment of steep rise of interest around the blockchain technology as it was just after the Bitcoin popularity explosion. It is a straight-forward and well-defined logical algorithm that was created to help to critically analyze which technology is better suited for a specific purpose and it was the first to distinguish between *public permissionless* and *permissioned* blockchain. The article is one of the first that gave definition and examples for the majority of the application field that even now are considered the most important for blockchain application, such as banking, payments, e-voting and intellectual property ownership (such as music or manuscripts). Even if this pipeline is not mainly focused on supply chain traceability, this application is taken in account and the authors focused on this topic, deeply describing the supply chain traceability and giving real world examples. An interesting one is about the applicability of a smart-contract based blockchain for a tamper-proof cold chain traceability scenario of a truck provided with IoT sensors that automatically upload data on a blockchain and the malicious system that can attack this application. Nevertheless, thanks to its versatility, this pipeline is the most suitable for the decision-making for the right technology to use for supply chain traceability and it was chosen as a base to develop the final pipeline published in Patelli and Mandrioli (2020).

Another interesting and well detailed pipeline has been designed by Koens and Poll (2018) (Fig. 4). The paper analyzes 30 different decision-making diagrams that should be fulfill the choice of the right technology, mainly from scientific works, including the previous mentioned work from Wüst and Gervais (2017), but it does also include some commercial ones (such as Gartner and IBM). After a global analysis and some comparisons of the most similar ones, it concludes that, generally, the commercial ones are less accurate and defined. The authors then proposed a new diagram that results in a very accurate and complete one, that can be considered an improvement of Wüst and Gervais (2017): however, despite its detail level, it is tailored to respond to the widest possible variety of cases, thus many proposed choices are focused on general purposes and economical transaction. In conclusion, this decision-making pipeline is even too detailed for the agrifood supply chain.

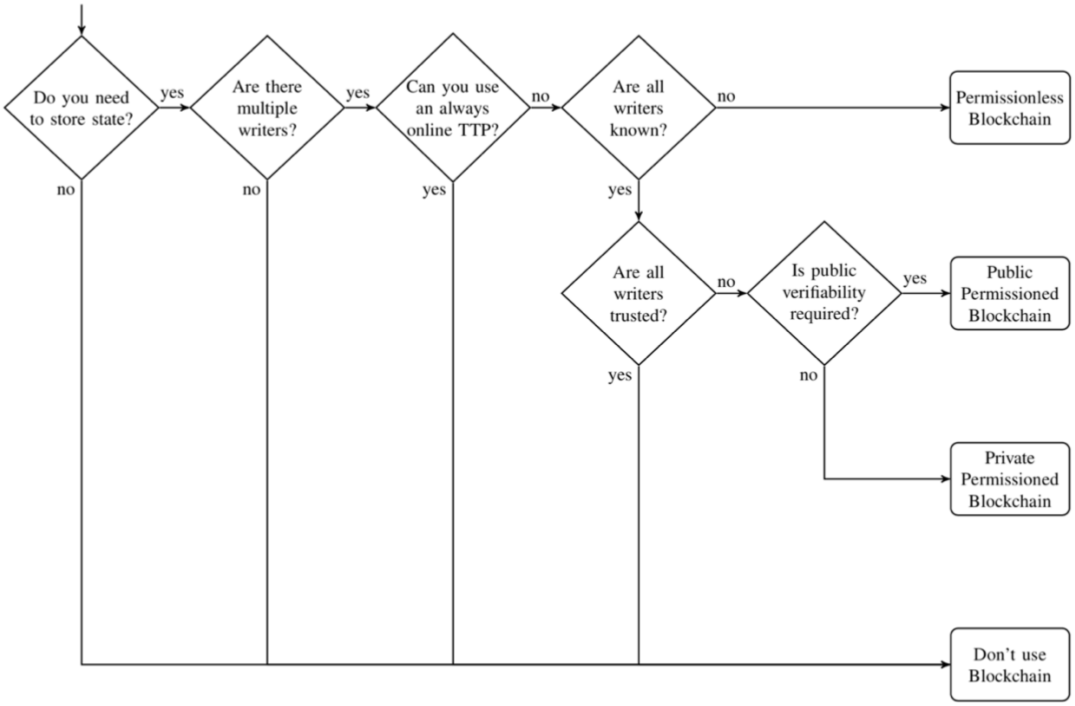

Fig 3. Decision-making tree from Wüst and Gervais (2017). This is the one chosen as a base for the final one. It is the most precise and straight-forward for the purpose of the food supply chain traceability.

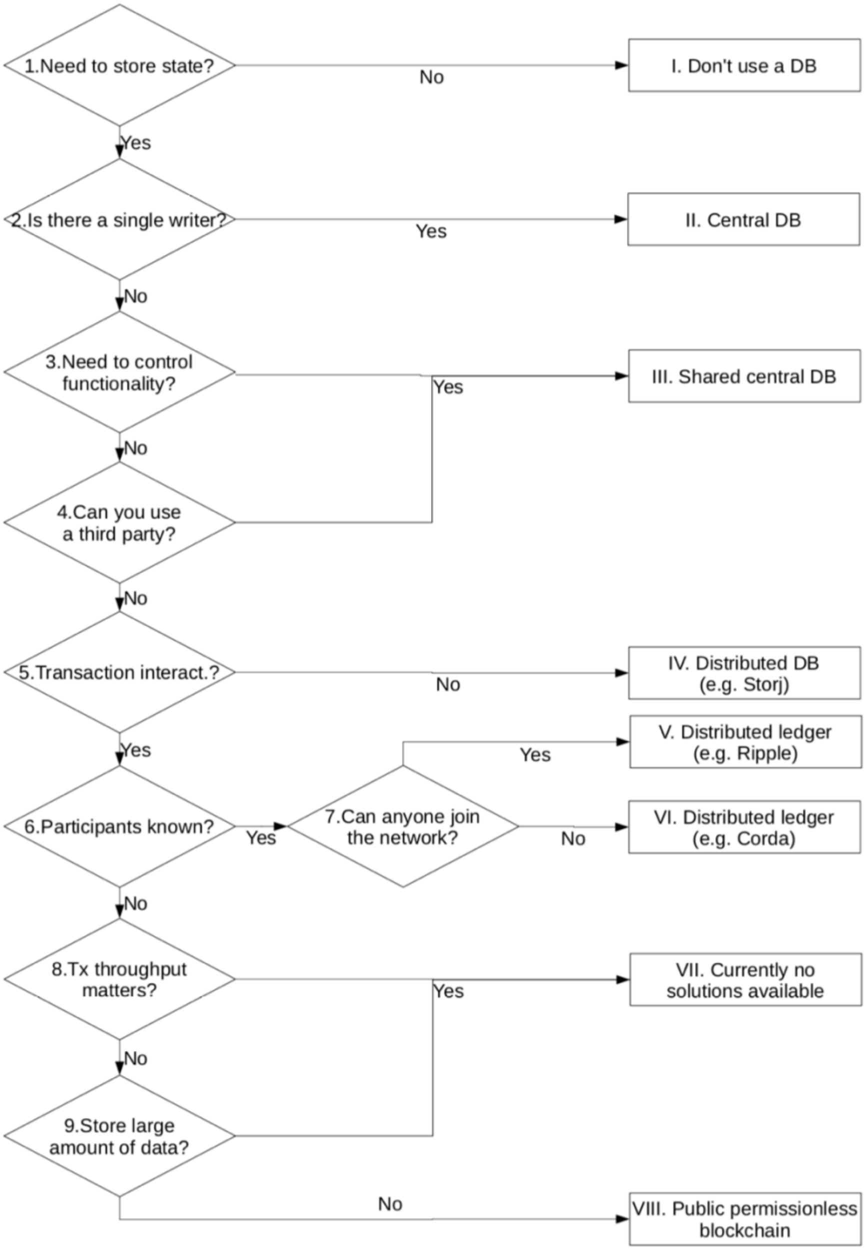

Fig 4. Decision-making tree from Koens and Poll (2018). Deep and complete, tailored for a wide variety of use cases. Too detailed, as it considers persmissionless blockchain and different databases which are not the best choice for the agrifood supply chain.

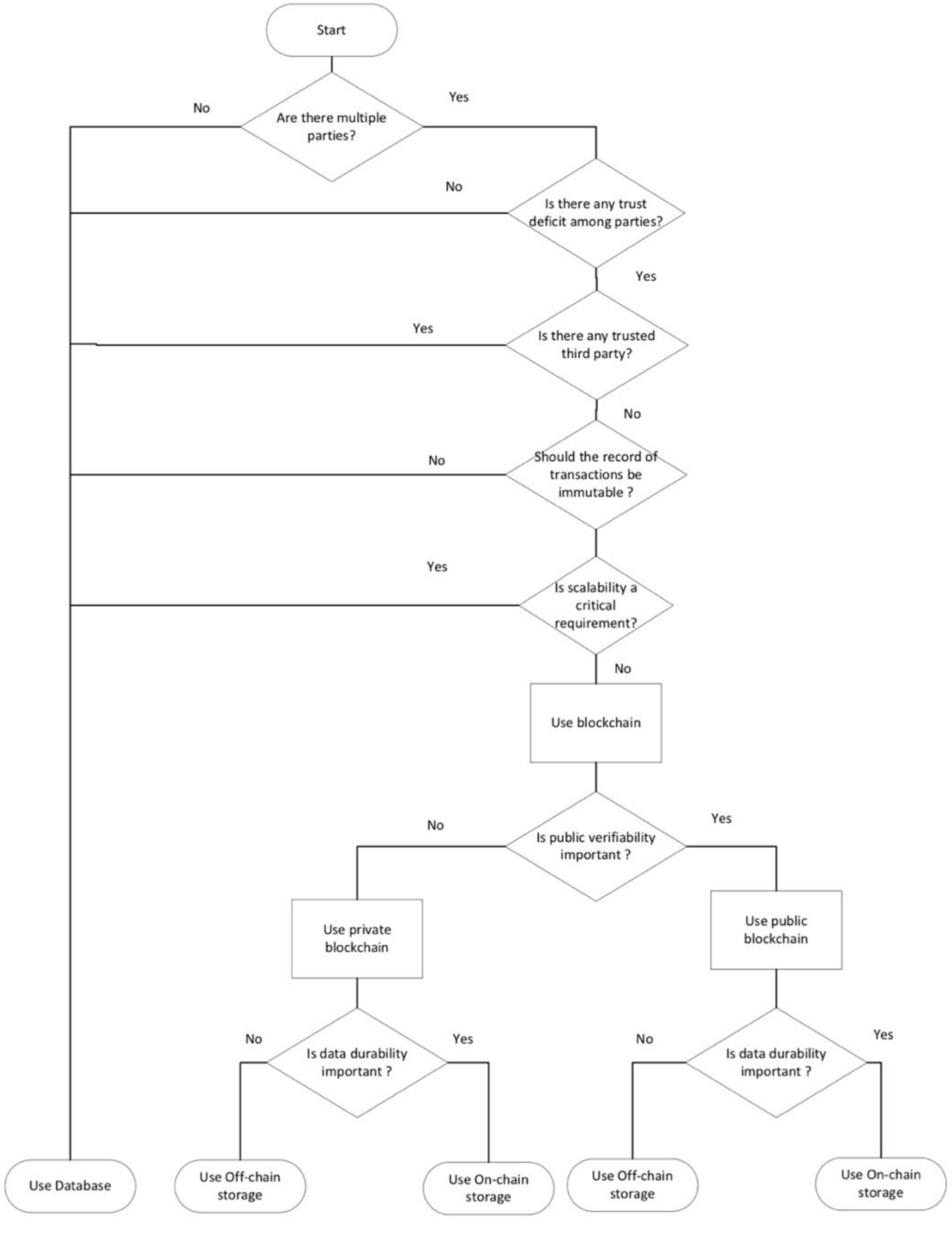

Fig 5. Decision-making tree from Chowdhuri et al (2018). Similar to Koens and Poll (2018), it is deep and complete. It has few issues and it is too focused on transactions and general purposes to be applied for the traceability of the food supply chain.

Chowdhuri et al (2018) presented a deep and detailed decision-making tree (Fig. 5), which correctly describes the decision process that should be followed for the choice of the blockchain for a variety of cases. It also includes a crucial factor, which is the scalability. This paper has been written in 2018 and as today, the scalability of these systems has not been completely solved yet. In particular, the transactions per second are considerably lower that other kind of database (such as credit card central management systems), especially for *permissionless* blockchains (Zhou et al., 2021), as well as issues related to block and chain size, block generation time and network latency (Nasir et al, 2022). However, these issues are quite important for banking and transactions, but less important for food supply chain traceability, as the majority of the described cases have their own blockchain and the transactions cannot be as massive as in the case of the *permissionless* cryptocurrencies. The other two problems that this pipeline presents are that the need for certified data should be considered before any other requirement, as it is the main purpose of the blockchain, and it does not consider *permissioned* blockchain, but only *public* and *private*. If *permissioned* blockchain can be considered as a peculiar kind of *public* blockchain, it is true that the requirement and the functioning are so different that a proper distinction has to be made.

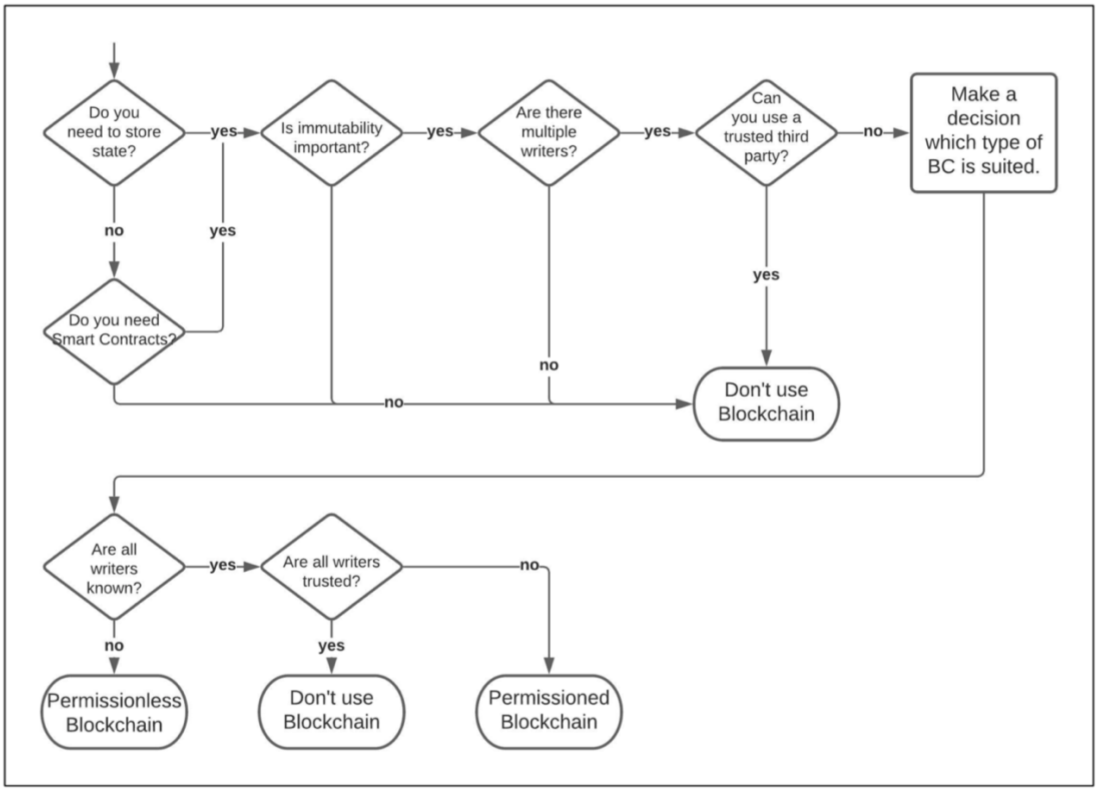

Fig 6. Decision-Making tree from Berneis and Winkler (2021). This flowchart was published after the release of the food supply chain in Patelli and Mandrioli (2020). Interesting and complete, as includes the need for smart contracts.

Berneis and Winkler (2021) studied a scheme (Fig. 6) that is particularly interesting. In their paper they a include a specific step for the need of smart contracts, which is a quite interesting one. They assesed the applicability of the blockchain technology for the traceability of luxury goods, healthcare, and food, showing that the luxury goods category is the one that would mainly benefit from an improved digital traceability. They stated that the value of data immutability for the food supply chain is lower than the other supply chains, and the benefit from the blockchain application increase when the product value is high, and the transactions are low. However, some food products have a considerable cost (such as DOP products as Parma Ham or Jamon Serrano) and some issues about the origin (Curzi and Huysmans, 2022), meaning that there must be at least a distinction among the food. However, the pipeline includes a specific step for the need of smart contracts, which is a quite interesting one. It is mentioned just after the need for stored state, but smart contracts must be considered also further down in the pipeline. Ultimately, this pipeline also includes the *permissionless* blockchain, which is not suitable for the food supply chain.

### The definitive pipeline

In conclusion, the version of the decision-making tree, modified from Wüst and Gervais (2018), proposed in Patelli and Mandrioli (2020) might still the most suitable one for the adoption of the blockchain in the food supply chain (Fig. 7).

In the proposed pipeline, a "writer" is considered to be any "entity with write access to the database/blockchain". In Wüst and Gervais (2018), unknown writers were admitted, whereas every actor involved in a food supply chain must be known. For this reason, the "unknown writer" option has been removed, together with the "*Permissionless* blockchain" option, which would not be suitable as in the food supply chain not anyone can have the right to write data in the system and the safety level would be excessive and resulting in a slower and heavier system.

The first parameter to consider is if certified data are needed. Certified data can include transaction details, as well as information that result important for the customers, such as country of origin, food safety and quality certification, production systems and animal welfare (Aboah and Lees, 2020). If there is no need to certify data, e.g. the use of the database is limited to additional information for the consumers, the use of a real blockchain would be unnecessary: in this case, any online database would sufficiently fulfil the requirements. If certified data are needed, is important to consider if there is more than one subject that writes on the digital traceability system. If two or more entities have the access to write data, the use of a real blockchain would be justified. Otherwise, even in this case, another lighter and faster time-stamped distributed database would suit better. The third parameter is to consider is if there is an always online Trusted Third Party (TTP). This TTP can function as a certificate authority if it is used to establish a known group of writers (Wüst and Gervais, 2018), making the security level and mechanism of the blockchain redundant. The fourth step is designed to verify if all the writers are trustable to each other, as many different food supply chains include different actors managed from the same company or group. As the blockchain design is tailored to solve trust issues, it would be redundant once again and a different kind of DLT should be considered. If all the previous conditions are verified, the last parameter to take in account is if the data are written to be *public* or not, or what is the purpose of the digital traceability system. The blockchain has to be *public* for any marketing reason or any kind of communication towards the consumers, whereas it can be *private* if the purpose is only to keep an internal register of all the transaction in the supply chain.

Blockchain has been tailored to fulfil high security level requirements in an environment in which the writers are unknown and supposedly malicious to each other (Nakamoto, 2008). In conclusion, the vast majority of the scenarios would not need a blockchain.

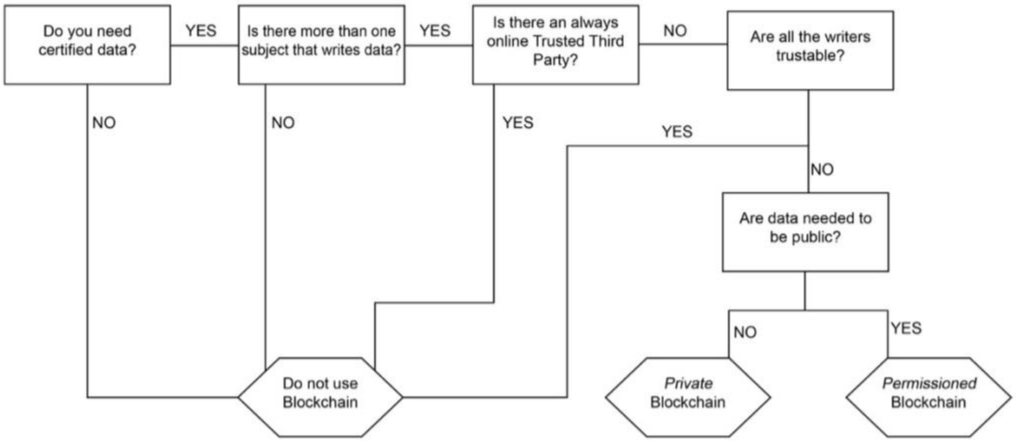

Fig 7. Decision-making tree from Patelli and Mandrioli (2020). It may represent the most suitable diagram for the adoption of the correct technology in case of food supply chain traceability.

An aspect that has changed in the last years is the suitability of the different blockchain platforms to the supply chain traceability. In the last years, blockchain scalability is improved and now there are some technologies which are being developed specifically for the supply chain traceability and represent a sort of standard, even if there is still a lack in relevant and well-described use cases.

The two most used platforms, Hyperledger and Ethereum reached a usability that is quite different from the first blockchains, which means that even if a blockchain may be redundant for a single-owned and only-actor supply chain, the mentioned platform offer a secure and safe database that works as fast as a non-blockchain time-stamped database.

Second, the *private* blockchain is used almost only for financial transaction, whilst *permissioned* blockchain has become the standard for supply chain traceability with few exceptions, such as the control over the respect of accepted religious practices (Cancer Zain et al., 2018) or the internal management and security of a supply chain with no interest in showing the traceability data to the public (Casino et al, 2019; Casino et al, 2020).

**Use case scenarios**

- Olio Nece (https://www.olionece.it/blockchain-traceability) is a use case of a blockchain provided by EZLab that "allows the consumers to verify chemical and organoleptic characteristic of the oil, as well as the entire supply chain by scanning a QR to access to the blockchain". By running the pipeline for this case, there is the need for certified data as the company wants to improve their traceability and show the complete process to the customers, thus this first step is fulfilled. However, the run stops at the second step, as the blockchain is controlled by a single user: it is not known exactly which technology has been used for this project, but it is advertised as a blockchain. A real *permissioned* blockchain is over-secure and it makes more sense to use a different database for any single-user or single entity with data entry privilege (Wüst and Gervais, 2018; Patelli and Mandrioli, 2020; Berneis and Winkler, 2021).
- Cantina Volpone is another collaboration of the Italian EZLab (https://placidovolpone.it/blockchain-vini/). It has been the first example of blockchain technology applied to the traceability of wine and it allows the consumer to access to a like origin, chemical and organic properties and all the other information on the supply chain that are usually unavailable to the customers. Nevertheless, this has two problems: the first is the

single owner, which makes the blockchain actually losing its real purpose (as stated before for Olio Nece), and the second is the non-suitability of the wine supply chain for blockchain-based digital traceability (as illustrated in the Fig. 2).

- Walmart Canada represent a different scenario. Walmart, the biggest retail company in the world, decided years ago to test the adoption of the blockchain to solve traceability problems for mango and pork meat and then extend its application to other supply chains (https://www.hyperledger.org/learn/publications/walmart-case-study). Walmart Canada adopted blockchain technology together with a distribution company and using IoT sensor and automated processes to track deliveries, to solve the problem that Walmart and these delivery companies do not talk to each other (Vitasek et al, 2022). If the pipeline is used for this case the two first steps are satisfied, as two or more companies need certified data. The third step is the one that is not possible to know: the precise system description is not available, and it may be wrong to assume whether there is or is not a TTP always online that can serve as a certificate authority. By assuming that there is this TTP, the blockchain makes no sense, but if there is not the run can go further and there is no trust between the parties as they do not talk to each other. Then, for the last step, the used technology is an Hyperledger *private* blockchain, thus the data will not be public. This example fulfills the requirement to be a good blockchain application *if* there is not a TTP.

- Regarding Saporare use case, here is the run on the decision-making tree. First, there is the need to certify data to improve traceability and, consequently, the trust of the potential customers and the producers by showing more transparency (Ferreira da Silva and Moro, 2021). There will be more than one writer, as each producer will enter the data for every batch uploaded in the Saporare ecommerce and Saporare will confirm the reception of that batch. Thanks to its architecture, Saporare acts as a third part in the supply chain, certifying the products by using S|Trace traceability system. There will not be any always online TTP (the data will be stored on Ethereum blockchain and not in a central server), and the parties have a limited trust in each other, as in such a system the trust can be easily altered, and it will be Saporare that will respond for any fraud or any kind problem that concern with the supply chain. Finally, the data will be public, in order to be shown to the customers. Saporare has as main goal to increase product value for traditional Italian food and, by means of an improved traceability, the increased information given to the customers will also allow their knowledge about the origin of their food, consequently increasing its value (Montecchi et al., 2019).

In conclusion, by running the decision-making flowchart for the Saporare and S|Trace use case, it shows how this use case represents the perfect example of application of the blockchain to the agrifood supply chain.

## Bibliography

- Aboah, J., & Lees, N. (2020). Consumers use of quality cues for meat purchase: Research trends and future pathways. *Meat Science*, *166*.
- Anastasiadis, F., & Alebaki, M. (2021). Mapping the greek wine supply chain: A proposed research framework. *Foods*, *10*(11).
- Berneis, M., & Winkler, H. (2021). Value Proposition Assessment of Blockchain Technology for Luxury, Food, and Healthcare Supply Chains. *Logistics*, *5*(4), 85.
- Cancer Zain, J., Tedja Nugraha, G., Didiet, R., Hidayat, R., Budiman, T., & Setiawan, A. (2018). *The Implementation of Halal Supply Chain With Private Blockchain in Indonesia*.
- Casino, F., Kanakaris, V., Dasaklis, T. K., Moschuris, S., & Rachaniotis, N. P. (2019). Modeling food supply chain traceability based on blockchain technology. *IFAC-PapersOnLine*, *52*(13), 2728–2733.
- Casino, F., Kanakaris, V., Dasaklis, T. K., Moschuris, S., Stachtiaris, S., Pagoni, M., & Rachaniotis, N. P. (2020). Blockchain-based food supply chain traceability: a case study in the dairy sector. *International Journal of Production Research*, 1–13.
- Chowdhury, M. J. M., Colman, A., Kabir, M. A., Han, J., & Sarda, P. (2018). Blockchain Versus Database: A Critical Analysis. *Proceedings - 17th IEEE International Conference on Trust, Security and Privacy in Computing and Communications and 12th IEEE International Conference on Big Data Science and Engineering, Trustcom/BigDataSE 2018*, 1348–1353.

- Curzi, D., & Huysmans, M. (2022). The Impact of Protecting EU Geographical Indications in Trade Agreements. *American Journal of Agricultural Economics*, *104*(1), 364–384.
- Ferreira da Silva, C., & Moro, S. (2021). Blockchain technology as an enabler of consumer trust: A text mining literature analysis. In *Telematics and Informatics* (Vol. 60). Elsevier Ltd.
- IBM Food Trust (2021). Available at www.ibm.com/blockchain/resources/food-trust/demo/trace
- Khalifehzadeh, S., Seifbarghy, M., & Naderi, B. (2015). A four-echelon supply chain network design with shortage: Mathematical modeling and solution methods. *Journal of Manufacturing Systems*, *35*, 164–175
- Khalifehzadeh, S., Seifbarghy, M., & Naderi, B. (2015). A four-echelon supply chain network design with shortage: Mathematical modeling and solution methods. *Journal of Manufacturing Systems*, *35*, 164–175.
- Koens, T., & Poll, E. (2018). What Blockchain Alternative Do You Need? *Data Privacy Management, Cryptocurrencies and Blockchain Technology*, 113–129.
- Leat, P., & Revoredo-Giha, C. (2013). Risk and resilience in agri-food supply chains: The case of the ASDA PorkLink supply chain in Scotland. *Supply Chain Management*, *18*(2), 219–231.
- Montecchi, M., Plangger, K., & Etter, M. (2019). It’s real, trust me! Establishing supply chain provenance using blockchain. *Business Horizons*, *62*(3), 283–293. https://doi.org/10.1016/j.bushor.2019.01.008

- Nakamoto, S. (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. *Https://Bitcoin.Org/Bitcoin.Pdf* . www.bitcoin.org
- Nasir, M. H., Arshad, J., Khan, M. M., Fatima, M., Salah, K., & Jayaraman, R. (2022). Scalable blockchains — A systematic review. *Future Generation Computer Systems*, *126*, 136–162.
- Pearson, S., May, D., Leontidis, G., Swainson, M., Brewer, S., Bidaut, L., Frey, J. G., Parr, G., Maull, R., & Zisman, A. (2019). Are Distributed Ledger Technologies the panacea for food traceability? *Global Food Security*, *20*(February), 145–149.
- Vitasek K., Bayliss J., Owen L., and Srivastava N. (2022). How Walmart Canada Uses Blockchain to Solve Supply-Chain Challenges. *Harvard business review*. Available at https://hbr.org/2022/01/how-walmart-canada-uses-blockchain-to-solve-supply-chain-challenges
- Wüst, K., & Gervais, A. (2017). Do you need a Blockchain? *IACR Cryptology EPrint Archive*, *i*, 375.
- Zhou, Q., Huang, H., Zheng, Z., & Bian, J. (2020). Solutions to Scalability of Blockchain: a Survey. *IEEE Access*, *8*, 16440–16455.

## Conclusions

Blockchain is becoming an old and quite known technology, as it has been developed in 2008. The earlier applications to the food supply chains are dated back in 2016, 5 years back from the conclusion of this study, but the blockchain technology did not have the explosion that many expected. Despite a large number of applications, it did not catch on. In fact, it is still considered a young technology, which stills at the early age of its development and use (OECD, 2021).

For years, most of the literature has been about theoretical applications value and many interesting and complete work reached the same conclusions. The main problems for the first applications of the Blockchain to the food supply chain were the cost increase, the interaction with pre-existent (legacy) systems, the connection between informatics and the real world, but most importantly the lack of standards (Galvez et al., 2018; Pearson et al., 2019). Despite the presence of several ongoing Blockchain case studies proposed by different companies (Hyperledger, IBM, Amazon and others), their number is still low in comparison to the large potential applicative value of Blockchain technologies to the agrifood supply chains and despite several remarkable works deeply analyzed the challenges and the problems that the adoption of the blockchain would represent, a considerable number of papers had a lot in common and a few works were really disruptive.

Bumblauskas et al. (2020) has been one of the first papers that deeply described a case of blockchain application, bringing details about the system architecture and analyzing the impact and the consumer interest and this may be a milestone for scientific literature. Then, the number of well described studies has been far less than expected, possibly due to the protection that the companies and the blockchain technology providers have. Cocco et al.

(2021) is another deeply detailed and well described study on the bread supply chain in Italy, but il lacks the impact on the consumers. This is another issue, as different studies (such as Violino et al., 2019), included this one, assessed their interest and their willingness to spend more for a guaranteed traceability, even if the increase is quite considerable.

This study provides for both a valuable case study that assess the suitability of the blockchain technologies for the traceability of the food supply chain and gives as many details as possible to deeply describing the project. It also proves that a real blockchain would make sense only if there is the need for certified data that *are certified from a third part*. It is true that with such systems it is the blockchain itself that acts as a validation (Cachin and Vukolic, 2017), but it does not make sense if there is only one writer (as in the case of Olio Nece and Cantina Volpone that have been previously described in this study).

It seems that, for some reason, a Blockchain-based traceability is, at present, not fully appreciated in some food industries, as this technology did not have the explosion that was expected and despite the utility that Blockchain would have for all the actors involved and for sustainability (Park and Li, 2021). Additionally, the demand for food involves relevant environmental burdens that have to be taken into account on the way to achieving the Sustainable Development Goals (Cambeses-Franco, 2022).

This wide adoption has not yet happened possibly not because the companies need to cover for scarce safety of the food products, as the regulation provides for a relevant analysis and protection framework (EFSA, 2021), but to the peculiar structure of some food supply chains that is actually different from what thought by consumers. For instance, some Italian products, including some foods labeled as Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI), are made using meat and/or raw material coming from geographically distant countries that could affect the “local” image of these products. An example could be the Bresaola della Valtellina, a traditional Italian meat-derived food, which has frequently been made using meat from different countries (Zappalaglio, 2018) for years. Is there any risk of making this product “less Italian” in the consumer’s mind if traced with public Blockchain projects?

Blockchain Technologies have a proven potential for the traceability of the agrifood supply chains, as assessed by several recent articles and case studies (Casino et al., 2020; Liu et al., 2021; Tsolakis et al., 2021; Stranieri et al., 2021; Cocco et al., 2021; Mercuri et al., 2021). Moreover, even if most of the ongoing Blockchain studies are still more similar to proofs of concepts than to real cases that can be routinely applied for the digital traceability of the supply chains, Blockchain Technologies are mature and robust technologies. At present, however, some barriers and challenges still exist, which hinder Blockchain popularity among farmers and food supply systems. In particular, it seems that an inadequate knowledge of the differences in terms of cost and complexity of the available Blockchain Technologies is making farmers and food supply systems not confident in adopting them. On the contrary, Blockchain Technologies are secure, reliable, and transparent tools to ensure food safety and integrity. Furthermore, improvements in the understanding about what and how the Blockchain data are stored and manipulated are essential to favor the adoption of Blockchain-based applications. Indeed, Blockchains favor the access to data in the agrifood supply chains, but also bring new challenges from a data management perspective (Kumar et al., 2021).

In order to favor Blockchain adoption in the agrifood supply chains, it is essential that each future case study of Blockchain-based traceability clearly illustrates data about the economic sustainability of the initiative and the outcomes of these projects. At the same time, some improvements are also requested from a policy perspective, because governments should encourage the growth of digital traceability -minded ecosystems in agrifood chains, supporting Blockchain Technologies and other Distributed Ledgers as part of the general goals of optimizing the competitiveness and ensuring the sustain-ability of the agrifood supply chain, as well as designing a clear regulatory framework for Blockchain implementations (Kamilaris et al., 2021).

The consumer opinion included in this study demonstrates the interest that the consumers would have in improved digital systems that guarantee for the origin and, in general, for all the supply chain steps, as well as the genuineness of the products and the interviewed consumers are almost all available to spend more for having all these steps guaranteed by trustable systems.

The Saporare-S|Trace case study represents a unicity in the blockchain panorama as in this case is a third part that guarantees for the authenticity of the data. Nevertheless, it is true that Saporare cannot guarantee for the data entered by the producers, but the data entered in the blockchain lack in legal value and Saporare will organize audits to certify the authenticity of the production. The lack of legal value is also a possible fault in the blockchain regulation framework, as the entities that enter the data can be fraudulent and, in that case, the blockchain would actually guarantee and secure what in reality is a lie. In the future, a regulatory framework that also takes in account such examples must be implemented.

Another relevant issue is the consumers' education, that must be designed to improve their sensibility and attention to the relevant matters around responsible purchase and sustainable development, as well as authenticity and safety of the food (Chen and House, 2021).

Blockchain can help as it may be useful to all the stakeholders involved in the supply chain. Consumers will have improved knowledge on the origin of the food, which means also that they would have an improved power of choice as they can buy more responsibly. The other advantage is to have an improved certainty to buy products that are really those products, thus an improved certainty of food authenticity.

Entities such as producers and consortiums could benefit from an improved transparency, as it will distinguish the most righteous industries as they can guarantee better, safer and more secure products.

Third part entities (such as EFSA or USDA) can have immediate access to the information added to the systems in case of any food safety or food fraud issues and consequently ease the biological, chemical, or genetic analysis.

At the end, it must be considered that Blockchain is only a technology. As for all the technologies, instruments, and techniques that human invents, the use that we make of it is important, much more than all the discussion over its design and possible applications.

## Bibliography

- Cachin, C., & Vukolić, M. (2017). Blockchain consensus protocols in the wild. *Leibniz International Proceedings in Informatics, LIPIcs*, *91*.
- Casino, F., Kanakaris, V., Dasaklis, T. K., Moschuris, S., Stachtiaris, S., Pagoni, M., & Rachaniotis, N. P. (2020). Blockchain-based food supply chain traceability: a case study in the dairy sector. *International Journal of Production Research*, 1–13.
- Chen, L. A., & House, L. (2021). Food lifestyle patterns among contemporary food shoppers. *International Journal of Consumer Studies*.
- Cocco, L., Mannaro, K., Tonelli, R., Mariani, L., Lodi, M. B., Melis, A., Simone, M., & Fanti, A. (2021). A Blockchain-Based Traceability System in Agri-Food SME: Case Study of a Traditional Bakery. *IEEE Access*, *9*, 62899–62915.
- Cristina Cambeses-Franco, Sara González-García, Gumersindo Feijoo, María Teresa Moreira. "Driving commitment to sustainable food policies within the framework of American and European dietary guidelines." Science of The Total Environment 807 (2022): 150894.
- EFSA. (2021). The European Union One Health 2019 Zoonoses Report. *EFSA Journal*, *19*(2).
- Galvez, J. F., Mejuto, J. C., & Simal-Gandara, J. (2018). Future challenges on the use of blockchain for food traceability analysis. In *TrAC - Trends in Analytical Chemistry* (Vol. 107, pp. 222–232). Elsevier B.V.
- Kamilaris, A., Cole, I. R., & Prenafeta-Boldú, F. X. (2021). Blockchain in agriculture. In *Food Technology Disruptions* (pp. 247-284). Academic Press.

- Kumar, A., Abhishek, K., Rukunuddin Ghalib, M., Nerurkar, P., Bhirud, S., Alnumay, W., Ananda Kumar, S., Chatterjee, P., & Ghosh, U. (2021). Securing logistics system and supply chain using Blockchain. *Applied Stochastic Models in Business and Industry, 37*(3), 413–428.
- Liu, Z. Y., & Guo, P. T. (2021). Supply chain decision model based on blockchain: a case study of fresh food E-commerce supply chain performance improvement. *Discrete Dynamics in Nature and Society, 2021*.
- Mercuri, F., della Corte, G., & Ricci, F. (2021). Blockchain technology and sustainable business models: A case study of devoleum. *Sustainability (Switzerland)*, *13*(10).
- OECD, 2021. G20 report on blockchain in global value chains. Report for the G20 digital economy task force. Trieste, Italy, August 2021.
- Park, A., & Li, H. (2021). The effect of blockchain technology on supply chain sustainability performances. *Sustainability (Switzerland)*, *13*(4), 1–18.
- Pearson, S., May, D., Leontidis, G., Swainson, M., Brewer, S., Bidaut, L., Frey, J. G., Parr, G., Maull, R., & Zisman, A. (2019). Are Distributed Ledger Technologies the panacea for food traceability? *Global Food Security*, *20*(February), 145–149.
- Stranieri, S., Riccardi, F., Meuwissen, M. P. M., & Soregaroli, C. (2021). Exploring the impact of blockchain on the performance of agri-food supply chains. *Food Control, 119*.
- Tsolakis, N., Niedenzu, D., Simonetto, M., Dora, M., & Kumar, M. (2021). Supply network design to address United Nations Sustainable Development Goals: A case study of blockchain implementation in Thai fish industry. *Journal of Business Research*, *131*, 495–519.

- Violino, S., Pallottino, F., Sperandio, G., Figorilli, S., Antonucci, F., Ioannoni, V., Fappiano, D., & Costa, C. (2019). Are the innovative electronic labels for extra virgin olive oil sustainable, traceable, and accepted by consumers? *Foods*, *8*(11).
- Zappalaglio, A. (2018). The puzzle of reputation in EU Protected Geographical Indications: Can traditional specialities guaranteed provide a solution?. *SSRN*.

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