Using Genomics Tools to Address Traceability Challenges in Agriculture and Agrifood

– POLICY BRIEF –

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Montréal – Octobre 2019

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Objectives of the Mandate Entrusted to QCBS by Génome Québec

To promote a better understanding and support decision making regarding issues of food traceability, Génome Québec asked the Quebec Centre for Biodiversity (QCBS) to produce a Policy Brief on the subject. This document is the result of a literature review and a discussion held within a focus group of five researchers from academia and government agencies. The views expressed herein do not necessarily reflect those of Génome Québec.

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1. Executive Summary

According to current projections, the global population will reach 9 to 10 billion people by 2050. This many mouths to feed will require the implementation of sustainable, innovative agricultural systems and a reliable food traceability system. Given the growth in international trade, it has now become more important than ever to ensure that food travelling across borders is safe for human health and, in cases of contamination, easily traceable along the supply chain.

Genomics can help improve the safety of our food. DNA barcoding, for example, can be used to determine the genetic identity of raw materials or ensure the safety of food by identifying any pathogenic microorganisms present in a plant- or animal-based product. Genomics offers methods of analysis that are unbiased since results are based on identifying a genetic marker specific to each animal or plant species found in a product. The speed and reliability of genomics tools also represent major assets compared to classical methods when it comes to identifying and tracking agricultural goods and their derived products (Galimberti et al., 2013), and responding to cases of food contamination or fraud.

Genomics tools are equally effective at accurately characterizing the DNA of harmful organisms, parasites and invasive species, which can cause significant economic, environmental and social damage. Consequently, these tools have the potential to become useful allies for the monitoring of parasitic diseases in livestock or identifying harmful organisms in aquatic environments and soils.

As a non-invasive system of monitoring, genomics technology can easily be integrated into other traceability procedures, including blockchain and existing or future certification systems. In addition, the reliability of results derived from genomics testing meets the need for all stakeholders – including consumers – to have access to credible information about food products.

Despite the many possibilities offered by genomics in the area of food traceability, certain challenges remain in terms of regulations, the validation of experimental analyses and the social acceptability of the technologies according to consumers and industry.

This document describes recent needs in food traceability and presents the genomics tools available to meet existing challenges. It also provides policymakers with recommendations on enhancing food traceability in Québec and positioning the province as a global leader in the field.

Recommendations to Policymakers[1]

1. Establish a random sampling and testing system using genomics tools to guarantee the authenticity of the food consumed in Canada, especially seafood and its derived products (p. 11).

2. Develop legislation on labelling to improve traceability through the dissemination of accurate information across the distribution chain. Financial assistance should accompany these measures in order to offset any economic impact, particularly in the primary sector (p. 12).

3. Implement an effective recall system based on new DNA testing technologies in order to avoid recalling safe products (p. 13).

4. Implement a traceability system to assess biodiversity in agricultural environments and, in turn, promote sustainable farming practices and healthy ecosystems (p. 13).

5. Invest in DNA databases that have been thoroughly validated by a competent, independent authority to enable the characterization of local species and agricultural environments (p. 14).

6. Promote cooperation among experts (academia, private sector, government) to test the reproducibility of results and achieve standardization (p. 15).

7. Establish a network of standardized laboratories accredited by a credible, independent organization tasked with analyzing samples from various stakeholders in the system (p. 15).

8. Develop a legislative framework (based on prior consultation) to ensure that the validation of results derived from genomics tools are taken into consideration during legal proceedings (p. 15).

9. Develop an integrated system by focusing on existing gaps in the conventional traceability methods and incorporating genomics tools to ensure the accurate identification of a food product in cases potentially involving fraud or unsafe foods (p. 16).

10. Reach out to the public and agricultural and agrifood industry to identify the obstacles and opportunities involved in integrating genomics tools into traceability systems (p. 16).

11. Set up a committee to discuss the economic impact on the agricultural and agrifood industry of implementing genomics tools across the supply chain (p. 18).

[1] The above recommendations are not listed in any particular order of priority.

2. Background

2.1. Traceability and its Applications in Agriculture and Agrifood

Traceability is a procedure used to monitor a product throughout the various stages of its production, transformation and distribution (Dabbene *et al.*, 2016), and to collect relevant information across the distribution chain.

There are two traceability techniques: tracking and tracing. Tracking is a quantitative method used to monitor the location of a product and determine its provenance and destinations. Tracing, on the other hand, is a qualitative method used to pinpoint the causes of a quality issue, among other things (Ruiz-Garcia *et al*., 2010).

In the agricultural and agrifood industry, the main goals of an efficient traceability system are as follows (Charlebois *et al.*, 2014):

1) Ensure the safety of food.
2) Guarantee the authenticity of products.
3) Provide consumers with credible information on the composition of a product.

The concept of traceability also applies to the evaluation and monitoring of agro-ecosystems (Cristescu, 2014) – ecosystems used for agricultural purposes. To support sustainable development and successfully feed a growing global population, the agricultural and agrifood industry must ensure the continued proper functioning of ecosystems. It must face many challenges posed by anthropogenic pressures, climate disturbances and biotic changes, such as the movement of pest populations (Littlefair and Clare, 2016), while producing safe food that can be traced from farmland to kitchen.

2.2. Genomics Tools: New Allies for the Agricultural and Agrifood Industry

Industrial processing alters the basic characteristics of food products, making it impossible to identify them on the basis of morphology (i.e, their form and structure). In such cases, DNA analysis can be used to determine with great accuracy the various components of a product. This is because the DNA molecules detectable in each cell of an organism (animal, plant, microbe, etc.) are stable throughout its life cycles and capable of resisting most transformation processes (Gianni *et al*., 2015).

Genome-based tools are used to analyze DNA molecules in order to characterize the genetic code of living organisms, helping us to better understand and monitor them. The outcome of this analysis is unbiased since results are based on identifying the genetic marker specific to each animal or plant species found in a product. As a result, these tools can be useful across the distribution chain, right up to the consumer (Littlefair and Clare, 2016).

Doubts about the authenticity of a product? The **multiplex PCR technique**[2], among others, can be used to identify the various animal species (targeted or unknown) in a meat product such as sausage or ground meat. Unlike certain traditional testing methods, including chromatography, mass spectrometry, microscopy, enzymatic assay (to name just a few), which require the use of sophisticated equipment and tools, multiplex PCR is fast, easy and inexpensive (Mehrnaz, 2018; Ballin, 2010).

DNA barcoding, which is based on the amplification of short DNA segments, is an effective way to ensure the safety of food (Gianni *et al.*, 2015) through the identification of pathogens. This molecular tool can rapidly and accurately detect contaminants, such as *E. coli* or *Salmonella*. It can also be used to look for parasites and identify them at various stages of development (e.g., egg, larval, adult) in a single step (Elsasser *et al.*, 2009). DNA barcoding offers a significant advantage over classical methods, such as taxonomic research. Taxonomy requires parasitic larvae be grown in culture until they reach the stage of adulthood, a process that takes time and special environmental conditions such as temperature-controlled spaces (Littlefair and Clare, 2016).

Another type of DNA analysis is **metabarcoding** used for the accurate and rapid identification of the mix of species present in a sample. The potential of this approach, which involves parallelized sequencing capacity, is enormous. When combined with DNA barcode reference libraries, metabarcoding lets researchers identify, with a single test, all the species found in a sample. It can also do so much more quickly than traditional morphological identification (Cristescu and Hebert, 2018), which relies on reference databases that are often incomplete and in need of further development.

Moreover, with metabarcoding, short DNA markers or traces left behind by organisms in their environment during their life cycle can be used for analysis. These traces originate from dead individuals at different stages of development or from fecal matter. It is possible to detect an organism even once it is no longer active in an area, since its environmental DNA[3] (eDNA) can persist in the environment for a significant period of time (Littlefair and Clare, 2016). Consequently, metabarcoding can be used to accurately assess the biodiversity of an agro-ecosystem and monitor its evolution.

Here are a few ways metabarcoding is used in agro-ecosystems:

1. **Biodiversity and trophic interactions**
    - Samples of eDNA can be collected from water or soil within agro-ecosystems (Taberlet *et al.*, 2012). They can then be used to support other studies that aim to measure the impact of agriculture on species diversity and to learn more about these systems (Orgiazzi *et al.*, 2015).

[2] Multiplex PCR is defined as the simultaneous amplification of various areas of a DNA matrix using primers specific to the organisms to be detected.
[3] Environmental DNA comes from cellular material shed by organisms (through skin, excrements, etc.) in aquatic or land environments. This material can be sampled and monitored using molecular tools, such as metabarcoding.

- Researchers can examine trophic interactions within an agro-ecosystem (Pinol *et al.*, 2014). By analyzing the fecal matter of several bird species, for example, they can identify the main predator of pests living in a given ecosystem. This information can then be used to attract and retain target predators that play an important and effective role in biocontrol. (Karp *et al.*, 2014).

2. **Identification of Pests**
    - Crop damage from pests involves significant loss of revenue and threatens food security (Godfray *et al.*, 2010). The identification of vertebrate, invertebrate and weed pests is extremely important in commercial trade and domestic scenarios to control potential invasions (Littlefair and Clare*,* 2016).

3. **Identification of Parasites**
    - Many livestock diseases are directly related to parasitic infections (e.g., coccidiosis, cestodes and nematodes). After identifying the parasites and their transmission pathways, an effective treatment plan can be put in place (Littlefair and Clare, 2016). For example, the *Neospora caninum* parasite is a common cause of abortion in cattle around the world (Dubey, 2003). The definitive hosts of this parasite are domestic dogs and other canines, such as foxes and coyotes (Mc Allister *et al.*, 1998; Gondim *et al.*, 2004). Cattle can develop the disease after coming into contact with these animals. Genomics tools can help easily determine the source of the contamination by testing the fecal matter of canines that have come into contact with the cattle. Proper measures can then be implemented to resolve the situation.

2.3. The Use of Traceability Tools in Québec and Around the World

The University of Guelph examined the traceability systems of 21 countries from the Organization for Economic Co-Operation and Development (OECD) focusing on the regulations in force in each case. The researchers developed a three-category ranking scheme based on the quality of the traceability system. Countries of the European Union, Norway and Sweden were classed as superior. Australia, Canada, Japan, Brazil, New Zealand and the United States were ranked as average, while China's system was deemed poor (Charlebois *et al.*, 2014).

Despite their numerous benefits, genomics tools are still not used to any great extent within current traceability systems, at least not in Québec or Canada, where information registers are the preferred method. When testing is required, traditional methods, such as bacterial cultures in Petri dishes or the morphological identification of invasive species or pathogens, are often the first choice. These are time consuming and require significant taxonomic expertise. Sometimes, only immature life stages are present in the samples. In such cases, identifying the species involves rearing the samples to adulthood. Lack of time and expertise is also a problem when dissecting adult samples for identification (Littlefair and Clare, 2016).

Yet, slowly but surely, genomics is making its way into traceability systems.

The Canadian Food Inspection Agency (CFIA) uses genomics tools alongside the Safe Food for Canadians Regulations (SFCR) in the following situations:

1. To track outbreaks of foodborne illnesses by analyzing the DNA of illness-causing bacteria. The testing can narrow down the specific strains involved, which can then help identify the source of the contamination.
2. To efficiently detect invasive species that can rapidly destroy ecosystems. DNA technologies can be used to accurately identify an insect that is morphologically identical or nearly identical to other species.
3. To identify counterfeit food products, since DNA barcoding can validate the information on labels but also determine if other ingredients have been added.

The SFCR came into effect on January 19, 2019. It meets recognized international food safety and consumer protection standards, including the Codex Alimentarius (CFIA, 2019). These standards apply to people who import and export food products and to those who grow and harvest fresh fruit and vegetables intended for export or interprovincial trade. Since the implementation of the SFCR, it is now mandatory to create and conserve electronic or paper records to ensure that food can be tracked efficiently. The Regulation also reduces the time it takes to remove unsafe food products from store shelves. Businesses are therefore required to implement traceability measures to track food products upstream to their suppliers and downstream to the consumers who purchased them (SFCR, 2019).

In Québec, traceability programs are spearheaded by Agri-traçabilité Québec (ATQ). Several pilot projects on traceability have been implemented by the ATQ. In the case of strawberries, for example, the system aims primarily at improving tracing capacity and product recalls in case of crises through efficient and timely digital monitoring. The same principle is used for other crops, such as potatoes and tomatoes. In the area of meat traceability, ATQ uses identifiers comprised of an electronic radio-frequency identification (RFID) tag and a visual panel recognized by the Canadian Cattle Identification Agency. This traceability tool tracks an animal from birth to slaughter giving a variety of details (e.g., premises identification and movement reporting) throughout its life. With this system, however, tracking ends once the animal is slaughtered (Agri-Traçabilité Québec, 2011).

In January 2014, a pilot project on beef product traceability was implemented in Québec. The goal was to recommend, test and validate a traceability model that would include standardized information on beef products bought and sold at each link of the beef distribution chain. This upstream-downstream approach is a voluntary initiative that encourages businesses to share and store key information with their commercial partners. In other words, the project requires the involvement of many industry stakeholders. Yet at the moment, businesses are reluctant to invest in the necessary information tracking, as they appear to be waiting for market opportunities and obligations or government regulations to justify the investments involved. In fact, it has been argued that many technical solutions to meet industry needs already exist, but that businesses are often at a loss when it comes to implementing traceability systems (Blais *et al.*, 2014).

More recently, another pilot project, launched by Cargill, focuses on providing consumers with information on the exact path of their beef, from farm to fork. Cargill lists DNA testing and blockchain, an Internet database tool, as technologies that are well suited to food traceability (Bédard, 2017).

In 2013, the Ontario Cattle Feeders Association introduced a DNA-based traceability program using a SNP chip. It entails the development of a database containing the SNP profiles of every animal that has been slaughtered. With this program, every piece of meat labelled “Ontario corn-fed beef” can be traced back to the exact animal through its genetic profile, thus increasing consumer confidence in the product (Science Media Centre of Canada, 2014).

In Europe, eDNA is now accepted in court as ecoevidence (i.e., proof based on molecular identification to demonstrate the presence of organisms in a given environment). Regulations have been implemented to govern sampling and certified laboratories. In October 2000, the European Parliament adopted the Water Framework Directive (2000/60/EC), an initiative aimed at protecting the environment and improving the state of aquatic ecosystems (European Council, 2000). The directive recommends the use of metabarcoding as an identification tool (Civade *et al.,* 2016).

3. Issues Involving Food Traceability and the Health of Agro-ecosystems

3.1. Food Fraud: Ensuring the Authenticity of Products to Protect Consumers and the Agrifood Industry

Food fraud is defined as the partial or complete replacement, addition, removal or omission of ingredients in a product (Van Ruth *et al.*, 2017). It can also involve false claims on the origin of a food product or ingredient. Food fraud is a deliberate, intentional act for economic gain (Spink *et al.*, 2011) to reduce production costs. With voluntary substitution, fraudsters use cheaper industry by-products or imported raw materials to minimize costs (Cordella, 2013) at all levels of the supply chain. It generally occurs in slaughterhouses and processing plants, making retailers and consumers its victims.

In Canada, traffickers generally focus on products that can slip under the radar of public authorities and businesses. Regulatory agencies around the world are often at a loss when it comes to food fraudsters since existing laws do not afford them any powers of investigation (Borde, 2018). As a result, fraud involving fish and seafood is now rampant in Canada. Given improvements in transportation, storage and conservation, demand for these products has grown – but so have the illegal activities surrounding their supply (Costa Leal *et al.*, 2015). DNA tests on fish products conducted at the Université Laval genetics lab in 2013 revealed that 47% of the 167 samples collected from restaurants and fish shops were improperly labelled. Some twenty varieties of fish were tested, including those suspected of being substituted with a less expensive or lower quality variety, such as cod, char, tuna, sole, red mullet, snapper or Pollock (Dussault, 2017). In sushi restaurants, 41 samples of Bluefin tuna were tested and only one was found to actually be Bluefin; the others had been replaced with escolar or less expensive tuna species such as albacore or bigeye tuna. Since these substitutes all have red flesh, they can easily pass as real Bluefin tuna, which is double the price. Moreover, samples of sole collected in restaurants revealed that 14 of them had been replaced with plaice or flounder (Dussault, 2017). According to some authors, 13 to 67% of halibut on the market is actually flatfish (*Pleuronectidae*) (Willette *et al.*, 2017). Consumers are the real victims here, since they are not able to distinguish these cheaper varieties.

To a lesser extent, all food products that are in high demand are exposed to the possibility of food fraud. The practice leads to a reduction in the nutritional and functional quality of the food in question. Product substitution can also have serious consequences when allergies or drug or supplement interactions are involved. An investigation into herbal products showed that 59% of them contained ingredients not listed on the label – a violation of existing regulations (Newmaster *et al.*, 2013).

According to the same study, this situation has consequences in the area of complementary medicine, among others, where the demand for medicinal herbs is experiencing strong growth, particularly in North America. The ingredients in some of these products can be contaminated or substituted with other plant species, such as rice, soy or wheat. The World Health Organization (WHO) considers this type of fraud to be a threat to consumer safety. Genomics tools can be used to test the integrity of products with great accuracy.

RECOMMENDATION 1

Establish a random sampling and testing system using genomics tools to guarantee the authenticity of the food consumed in Canada, especially seafood and its derived products.

Fraud is associated with more than just consumer safety; it also has an economic impact, since clients are paying full price for a substitute of lesser value. Food fraud is strongly correlated with the price consumers are willing to pay for a given commodity (Gianni *et al.*, 2015). The more expensive the product, the more likely it is to be substituted with cheaper replacements. In Québec, there have been a few isolated cases involving red meat and the illegal sale of wild game, but the main risk for fraud affects imported goods whose appearance and form will not be affected by a substitution.

Combating food fraud relies, first and foremost, on the identification of fraudulent products, whether they contain a single ingredient or a mix of ingredients. Genomics tools, given their sensitivity and accuracy in identifying plant or animal species in a product, offer a great opportunity in this respect.

However, finding the digital fingerprint that guarantees the authenticity of a given food product is no easy task. Despite the undeniable benefits of genomics tools, their use does come with some limitations. They cannot be used for cases of fraud involving the dilution of a product or the replacement of a wild fish with a farm fish, rather than a substitution. In some cases, it is not a question of food safety, but rather of consumers having to pay for products that do not match the label and that they did not choose.

RECOMMENDATION 2

Develop legislation on labelling to improve traceability through the dissemination of accurate information across the distribution chain. Financial assistance should accompany these measures in order to offset any economic impact, particularly in the primary sector.

3.2. Food Security: Ensuring Food Safety and Improving Response in Cases of Contamination

The concept of food security refers to the possibility for individuals to have physical, social and economic access to a sufficient quantity of safe and nutritious food to meet their dietary needs and food preferences (El Bilali, 2019).

From time to time, the food industry is rocked by a scandal involving contaminated food. This occurs due either to the intentional falsification of a product (e.g., horsemeat in beef products), as seen in section 3.1, or to a non-intentional incident involving the presence of micro-organisms (*Listeria, Salmonella, E. coli*) in a product (Barnett, 2016). Health problems caused by contaminated food are common and underestimated and foodborne illnesses can make many people sick. According to the scientific literature, less than 5% of such cases are recorded or reported to oversight agencies by consumers or public health workers. In 2012-2013, reporting of cases of foodborne contamination to the MAPAQ involved 4,313 people presenting symptoms of gastroenteritis potentially linked to tainted food (Ramsay et Delisle, 2013). The use of genomics tools for the taxonomic identification of pathogens during a food-related scandal, such as the avian influenza crises, can prove extremely valuable for preventing zoonotic diseases (illness transmitted from animals to humans) (Mehrnaz *et al.*, 2018).

RECOMMENDATION 3

Implement an effective recall system based on new DNA testing technologies in order to avoid recalling safe products.

Genomics tools are also useful for detecting and measuring potential harmful allergens in processed products. DNA barcoding, for instance, can identify species of nut trees that can trigger allergic reactions (Madesis *et al.*, 2012), which can cause dangerous respiratory problems, even when only traces of the allergen are present (Gianni *et al.*, 2015).

Identifying the geographic provenance of products is another way in which genomics can be helpful. Technologies used for this purpose include PCR fingerprinting and DNA sequencing of bacterial populations. Analyses can be carried out with geochemical tools, including trace element fingerprinting (TEF), which differentiates populations through the study of their mineral composition profile. Fatty acid analysis is another available option, since the lipid composition of a species is connected to its environment (Costa Leal *et al.*, 2015). Additional non-genome-based tools, such as radiogenic strontium (SR) isotope analysis, can also be used to determine geographic origin (Desrochers, 2012).

3.3. Agro-System Health: Better Understanding Through Genotyping

Among the organisms found in agro-ecosystems, some have the capacity to attack crops or spread pathogens that can be transmitted to humans. Despite their significant economic and environmental impact, these organisms have yet to be systematically studied. Our knowledge of their taxonomy is lacking, thus significantly limiting our ability to describe the biodiversity of agricultural environments and predict the evolution of the communities of organisms in response to global changes (Janzen, 2004; Condon *et al.*, 2008; Janzen, 2010).

RECOMMENDATION 4

Implement a traceability system to assess biodiversity in agricultural environments and, in turn, promote sustainable farming practices and healthy ecosystems.

Crop damage caused by invasive species accounts for major economic losses and threatens food security for the most vulnerable communities. According to Environment Canada, invasive species cost the agricultural and forest industry $7.5 billion in lost revenue every year *(Canadian Council on Invasive Species, 2018)*.

The most robust defence against invasive species is to detect them as soon as they arrive on the scene. The problem is that many species of insects look alike and identifying them properly under a microscope requires a high level of expertise. The job is all the more challenging when microscopic pathogens are involved, since the identification process can take several days, jeopardizing the cargo from where they came (GRDI, 2015).

It is also just as important to ensure that products destined for export are free of harmful organisms. New sequencing technology makes it possible to simultaneously identify several different species found in a mixed sample, even when these species are morphologically identical to one another – not to mention that the testing is much faster than traditional methods (GRDI, 2015). With DNA barcoding, invasive species can be identified rapidly and accurately (Comtet *et al.*, 2015). The main impediment to using this procedure is related to the databases, which are often incomplete.

RECOMMENDATION 5

Invest in DNA databases that have been thoroughly validated by a competent, independent authority to enable the characterization of local species and agricultural environments.

4. Regulatory and Social Barriers to the Use of Genomics Tools in the Area of Food Traceability and Agro-Ecosystem Health

In Canada, a legislative framework would need to be developed if molecular evidence were to be taken into account during decision-making. To this end, stakeholders must be able to work with robust, well-validated databases in certified laboratories.

The scientific community must also reach a consensus on the use of common protocols to establish uniform sampling, preservation, storage and methodological validation standards in the lab including standardized markers (Cristescu and Hebert, 2018). The ability to interpret results depends primarily on the availability of databases that contain the reference species of interest. These reference libraries are constantly under development. In this respect, methods are improving and so are the tools, but it is difficult to establish standards in a constantly evolving sector.

RECOMMENDATION 6

Promote cooperation among experts (academia, private sector, government) to test the reproducibility of results and achieve standardization.

While sequencing may be fast, the analysis and interpretation of results require time, highly qualified personnel and powerful computer and database resources. Strict protocols, which are often specific to each piece of equipment, also need to be followed. Genomics technology is advancing at a rapid pace and employees are not always sufficiently trained to perform the required analyses. Furthermore, the resistance of lab personnel to new technology also comes into play.

RECOMMENDATION 7

Establish a network of standardized laboratories accredited by a reputable, independent organization tasked with analyzing samples from the various stakeholders in the system.

Achieving perfectly reliable results requires access to extensive databases, which can be difficult to share. Incomplete reference libraries and sequences derived from misidentified species means records can sometimes be uncertain for a given species under study (Cristescu and Hebert, 2018). These data must also respect livestock and crop conditions and result from standardized sampling and analysis. Even though progress is being made, it is nevertheless still a challenge to translate new genomics technologies into undisputed interpretations required to confront fraudsters in court. Sampling, preservation, replication, methodological validation and interpretation can all be disputed during legal proceedings.

RECOMMENDATION 8

Develop a legal framework (based on prior consultation) to ensure that the validation of results derived from genomics tools is taken into consideration during legal proceedings.

One of the points made by the experts consulted during the discussion group was the idea that the use of genomics tools should complement existing traceability systems. At the moment, recourse to specification manuals certified under the Act respecting reserved designations and added-value claims is the only way to ensure the designation of a product. A pilot project has been launched with a few agricultural and agrifood sectors to characterize the microbiomes of certain foods (e.g., specialty cheese) in order to promote and better understand their relationship with the Québec terroir. This could provide a valuable opportunity to develop unique expertise. There are, however, obstacles when it comes to implementing genomics technologies. Even though the procedure itself is fast and easy, data processing can sometimes be fastidious. Not all genomics tools have reached their full maturity and sequencing can be a time-consuming task.

RECOMMENDATION 9

Develop an integrated system by focusing on existing gaps in the conventional traceability methods and incorporate genomics tools to ensure the accurate identification of a food product in cases potentially involving fraud or unsafe foods.

Public interest in food and agro-ecosystem health is an important driver in terms of finding solutions to improve food traceability in Canada. However, the implementation of new tools requires the cooperation of the agricultural and agrifood industry. Consequently, it is critical to gain a better understanding of the perceptions and concerns of industry stakeholders and the general public on the use of genomics tools.

Are consumers ready to pay more for products that are more easily traceable? The answer seems to be "yes," if the traceability system can guarantee product quality (Hobbs, 2005). If this is so, it will be extremely important to explain, in advance, the rationale and benefits of new technologies compared to existing tools, as well as the additional costs associated with an integrated traceability system designed to improve the safety of the food we eat.

RECOMMENDATION 10

Reach out to the public and the agricultural and agrifood industry to identify the obstacles and opportunities involved in integrating genomics tools into the traceability system.

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5. Conclusion

5.1. Towards Integrated Approaches to Better Food Traceability and Agro-Ecosystem Health

An outdated traceability system compromises the ability of consumers to meet their specific dietary needs and make enlightened food choices for themselves. The public wants to know how, where and when a food item was harvested or produced (Gianni *et al.*, 2015). Consumers are increasingly concerned about product authenticity and they worry about potential food fraud (Charlebois *et al.*, 2017). These concerns drive the establishment of reliable laws and procedures designed to assess the quality of food across the supply chain.

Developing an integrated approach to food traceability is an important opportunity to ensure consumer protection. This type of traceability must motivate and bring together the stakeholders of the agricultural and agrifood industry to find solutions adapted to the realities of today (Blissett, 2007), while taking into account the dynamic of product and information supply chains.

Blockchain is a food traceability system designed to restore consumer confidence in various food products. This system provides transparency, safety and authenticity. Stakeholders record their data, which are then verified and encrypted, making the information practically impossible to delete. Each information block refers to the prior block, thus ensuring the reliability of the data as a whole by forming a sequence of unalterable blocks. All stakeholders have access to the system, meaning that any false statement made will be detected quickly. Given that the information in each block is interconnected, any attempt at manipulating the data invalidates the entire chain. It is a decentralized system that does not involve third-party management. The blockchain stores, in a tamper-proof computer system, the transactions involving food and ingredients across the supply chain (Denuit, 2018). Genomics tools could be easily integrated into this type of system to increase its efficiency and reliability. Random tests or analyses carried out when product quality is in doubt could be done to control and validate the efficiency of the blockchain.

Metabarcoding technology is a promising avenue to evaluate and monitor the health of ecosystems and advance research into biodiversity. With the growing population, agro-ecosystems are increasingly solicited to produce a greater quantity of quality food, while respecting the environment and preserving natural resources. To protect soils and restore degraded land, careful monitoring is required. In addition to the adoption of sustainable farming practices by agricultural producers, a biosurveillance systems to monitor the health of ecosystems could be established to measure the loss of biodiversity in intensively farmed areas and characterize the microbial diversity in an agro-ecosystem. Genomics tools can help us better understand and find solutions to the food and environmental challenges of today and tomorrow.

In conclusion, a traceability system must provide concrete and appropriate incentive measures, rather than coercive ones, to ensure the compliance of the parties involved. If the program is not developed in a way that secures the consent of all stakeholders, it will be ineffective, regardless of its structure (Sanderson *et al.*, 2006). In other words, solid knowledge of the repercussions of an integrated system on the industry, particularly the cost of implementing it across the food chain (producer, processor, retailer and consumer) is needed so that the responsibility can be shared equally.

RECOMMENDATION 11

Set up a committee to discuss the economic impact on the agricultural and agrifood industry of implementing genomics tools across the supply chain.

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