

Microbial Food Safety and Sustainability

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Improving the environmental sustainability of the food supply chain will help to achieve the United Nations Sustainable Development Goals (SDGs). This environmental sustainability is related to different SDGs, but mainly to SDG 2 (Zero Hunger), SDG 12 (Responsible Production and Consumption), SDG 13 (Climate Action), and SDG 15 (Life on Land). The strategies and measures used to improve this aspect of the food supply chain must remain in balance with other sustainability aspects (economic and social).

fruits

vegetables

life cycle assessment

food losses

pathogens

foodborne disease

One Health

1. Overview

Improving the environmental sustainability of the food supply chain will help to achieve the United Nations Sustainable Development Goals (SDGs). This environmental sustainability is related to different SDGs, but mainly to SDG 2 (Zero Hunger), SDG 12 (Responsible Production and Consumption), SDG 13 (Climate Action), and SDG 15 (Life on Land). The strategies and measures used to improve this aspect of the food supply chain must remain in balance with other sustainability aspects (economic and social). In this framework, the interactions and possible conflicts between food supply chain safety and sustainability need to be assessed. Although priority must be given to safety aspects, food safety policies should be calibrated in order to avoid unnecessary deleterious effects on the environment. In the present review, a number of potential tensions and/or disagreements between the microbial safety and environmental sustainability of the fresh produce supply chain are identified and discussed. The addressed issues are spread throughout the food supply chain, from primary production to the end-of-life of the products, and also include the handling and processing industry, retailers, and consumers. Interactions of fresh produce microbial safety with topics such as food waste, supply chain structure, climate change, and use of resources have been covered. Finally, approaches and strategies that will prove useful to solve or mitigate the potential contradictions between fresh produce safety and sustainability are described and discussed. Upon analyzing the interplay between microbial safety and the environmental sustainability of the fresh produce supply chain, it becomes clear that decisions that are taken to ensure fresh produce safety must consider the possible effects on environmental, economic, and social sustainability aspects. To manage these interactions, a global approach considering the interconnections between human activities, animals, and the environment will be required.

2. Fresh Produce

Fresh produce is being increasingly recognized as a source of foodborne outbreaks [1][2]. The burden of such outbreaks includes economic losses, healthcare costs, loss of productivity, reductions in the quality of life, and mortality [3]. Using data from foodborne outbreaks that occurred between 1998 and 2018 in the USA, the Centers for Disease Control and Prevention linked a significant proportion of the illnesses caused by three key pathogens (*Salmonella*, *Escherichia coli* O157, and *Listeria monocytogenes*) to produce (including fruits, sprouts, vegetable row crops, and seeded vegetables) [4]. According to a report from World Health Organization (WHO) and Food and Agriculture Organization (FAO) [5], fruits and vegetables are among the main identified vehicles of foodborne Shiga-toxin-producing *E. coli* (STEC) illness. Regarding the economic losses, the study by Mackenzie and Apte attributed the costliest food recalls in the USA, involving losses of hundreds of millions of dollars, to fresh produce (tomato, spinach) [6]. As a consequence of such a situation, the fresh produce industry, governmental institutions, and researchers all around the world are seeking ways to guarantee the microbiological safety of such products. The Center for Produce Safety (Woodland, CA, USA) is an example of an organization managing this collaboration to fill knowledge gaps in the food safety of produce (<https://www.centerforproducesafety.org/> accessed on 16 July 2021). In the present work, the term fresh produce includes fresh (not subjected to thermal treatment) unprocessed and minimally processed fruits and vegetables. Frozen or dried fruits and vegetables are not within the scope of this work, although some of the concepts and discussions presented are to a certain extent applicable to those food items.

The impact that all human activities (including efforts to ensure food safety) have on environmental, social, and economic sustainability needs to be assessed [7]. In the framework of the present review, the term "sustainability" refers mainly to environmental sustainability. However, whenever possible, information regarding other aspects of sustainability (economic, social) has been included. The topic of food safety is related to most of the United Nations Sustainable Development Goals (SDGs) [1], especially with SDG3, which deals with good health and well-being [8].

Unfortunately, the fresh produce supply chain stakeholders on certain occasions receive conflicting recommendations concerning environmental sustainability and guaranteeing food safety [9]. The hierarchy between safety and sustainability is clear, with priority for the former [10]. However, numerous studies have suggested that taking decisions considering only food safety leads to inefficient strategies that do not achieve the proposed goals and can have negative consequences in other aspects such as environmental sustainability [11][12][13]. A global approach including co-management for food safety and sustainability (not only environmental but also economic and social) is put forward as the best strategy to deal with the potential conflicts [8]. For example, in the primary production step, keeping areas with natural vegetation in the agricultural lands could help to maintain an equilibrium between food safety and environmental and economic concerns [12]. Decision-making tools that integrate the different aspects involved (food safety, food quality, energy and water consumption, and environmental and economic impacts) are needed for optimum management of the supply chain [11][14].

3. Approaches, Strategies and Solutions to Solve Conflicts between Fresh Produce Microbial Safety and Environmental Sustainability

Co-management at the farm level comprises balancing environmental protection with food safety and productivity goals [15]. Certain types of agricultural management, such as organic agriculture and, particularly, biodynamic agriculture, which fosters the diversity of plant and animal life, increase the health and resilience of the organism farm. Biodynamic farms aspire to generate their fertility through composting, integrating animals, cover cropping, and crop rotation [16].

The work by Crohn and Bianchi [17] identified the assessment of the fate of pathogenic microorganisms in farmlands as the most urgent research topic regarding the co-management of food safety and surface water quality. In the last two decades, the information available on the behavior of pathogenic microorganisms in agricultural settings has increased significantly, mainly based on controlled tests with the inoculation of lab-prepared pathogens [18]. The development of methods for the large-scale affordable detection of pathogenic microorganisms in the agricultural environment would be of enormous help in tracking the sources of produce-borne outbreaks, as well as in the assessment of the fate of pathogens [19]. Information obtained directly from the environment would provide us with a more reliable picture of the situation, which could then be used as a background for the development of recommendations and legislation. Currently, one of the tools assessed to detect fecal contamination in fresh produce in the growing fields is hyperspectral imaging. Cho et al. evaluated this technique for the on-site detection of fecal contamination in romaine lettuce, with positive results [20]. Until more detailed and complete information on this topic becomes available, a conservative approach is likely to be taken by the competent authorities and by supply-chain stakeholders to avoid outbreaks and the subsequent consequences on public health and the agri-food sector [21][22].

In many cases, the experimental studies focus on a topic with a narrow approach, without considering interactions with other aspects. For example, over the years, numerous studies have assessed the efficacy of antimicrobial treatments that are applicable to fresh produce, without considering aspects such as the economic and environmental sustainability of their usage. However, in the last decade, studies with a more global perspective have been performed. Vigil et al. [23] assessed sanitation and decontamination techniques for fresh-cut produce using a life cycle approach. Papoutsis and Edelenbos [24] reviewed different sustainable post-harvest treatments for carrots (considering both human health and the environment). On the topic of food-waste reduction, Tromp et al. [25] assessed the potential reuse of salads in salad bars considering safety and quality. Yam and Takhistov [26] also considered microbial safety, as well as economic and environmental sustainability, when assessing an alternative packaging technology for fresh produce. Looking to the future, both available and innovative technologies (e.g., nanotechnology) will help to make fresh produce safety and sustainability compatible [27].

Proper traceability is crucial in the management of the fresh produce supply chain to ensure safety and avoid loss and waste [28]. Being able to quickly trace back any contamination to its source can reduce food loss/waste by defining precisely which lots should be disposed of, thereby avoiding the unnecessary elimination of uncontaminated batches [6]. The suitability of the use of blockchain technology to enhance traceability (and therefore the safety and sustainability) of fresh produce is being assessed [29].

In the conflicts between sustainability and safety, from the political organization's standpoint, there is a lack of a global perspective. Different departments, agencies, etc. have different and narrow-sighted ideas on how to deal with the issues of safety and sustainability (environmental, economic, and social) of the food supply chain [12][13]. Multiple criteria decision analysis has been suggested as a structured tool for decision-making in this complicated framework [14]. Regarding the concept of food safety, Leib and Pollans [12] proposed a more global view that should include not only the current concept (acute risks linked to ingestion of pathogens or toxins) but also other issues such as the health risks associated with cumulative ingestion and the health risks linked to the life cycle of food from production to end of life. Furthermore, measures aimed at improving fresh produce safety should be adapted taking the diversity of agrifood systems into account [7]. The One Health approach, based on the concept of the interconnection between human beings, animals, and the environment, promotes the formation of multidisciplinary teams that can work to obtain solutions to challenges that involve health, social, and environmental issues [8][30]. Finally, to promote the safety, security, and sustainability of the produce supply chain, the training and education of all the stakeholders are crucial [31].

4. Conclusions

Clear conflicts arise when analyzing the interactions between environmental sustainability and microbial safety of the fresh produce supply chain. Although the safety aspect has priority, the decisions taken for the sake of fresh fruit and vegetable safety ought to consider the potential impacts on the whole sustainability (environmental, economic, and social). The present work provides examples of frictions between microbial safety and environmental sustainability in the fresh produce supply chain. The stated issues are present throughout the supply chain (pre-and post-harvest) and affect all the different stakeholders (from primary producers to consumers). A global approach to deal with these safety/sustainability interactions is required. Widening the concept of food safety, co-management, multicriteria decision analysis, technological advances (e.g., cold chain management), working in multidisciplinary teams, and training the stakeholders are some of the strategies and approaches that will help to deal with sustainability/safety conflicts. In this context, the concept of One Health applied to the fresh produce supply chain appears as a correct approach to analyze and make decisions aimed at solving these challenges.

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