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Food Waste Causes in Fruit and Vegetables Supply Chains

Giulia Bartezzaghi[a*], Alessia Cattani[a], Paola Garrone[a], Marco Melacini[a], Alessandro Perego[a]

[a]*Politecnico di Milano DIG, via Lambruschini 4b, 20156 Milano, Italy*

Abstract

Fruit and vegetables are a core component of healthy diets, but horticultural production and distribution activities suffer from a high incidence of surplus food and food waste. The intrinsic perishability of products as well recurring pests, diseases and contamination events are since long recognized to be primary reasons for fruit and vegetables wastage, but a more thorough knowledge of causes, including external events and internal strategies and practices, is necessary to design and implement waste reduction strategies. However, literature on waste causes in fruit and vegetables supply chains is rather fragmented. Most existing studies focus on single products, single deterioration mechanisms or single reuse or recycling choices, and hardly ever investigate more than one stage of the fruit and vegetables supply chain.

The main objective of the paper is to offer an instrument for identifying in a comprehensive way the possible origin points and root issues behind food waste generation in the stages of fruit and vegetables supply chains. The research is conducted through the application of two methods. A first phase consists in a deep literature review, whose results are summarized in the so-called Causes Framework. This qualitative instrument shows the possible sources of fruit and vegetables surplus and waste, highlighting for each supply chain stage the high-priority causes and for each cause the fundamental root issue. The second research phase is a case study that shows how the Framework can be applied to pinpoint the most significant causes for specific supply chains. The unit of analysis is the supply chain of an Italian PGI pear. Primary information is gathered from 6 enterprises through 7 semi-structured interviews. The most critical causes of surplus and waste generation in the focal supply chain are found as the intersection between interview answers and Framework predictions. The paper integrates sparse pieces of knowledge on the processes of food waste generation in fruit and vegetables supply chains, and offers an instrument that may support private and public decision-makers in the reduction of horticultural waste.

Keywords: food waste causes; fruit and vegetables; supply chain; pear.

* Corresponding author. Tel.: +39-02-2399-2400
E-mail address: giulia.bartezzaghi@polimi.it

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1. Introduction

The present paper investigates the causes of surplus food (SF) and food waste (FW) generation along the fruit and vegetable (F&V) supply chain, from agricultural production to retail stage, with a focus on developed countries. The final objective is the development and proposal of an instrument, called Causes Framework (CF), for identifying the sources of SF and FW in F&V supply chains and for understanding the different issues underlying FW generation.

For the purpose of this paper, SF is defined as safe and edible food that in any stage of the supply chain is not sold to or consumed by the originally intended customer, while FW is defined as SF that is not reused in any form for feeding humans (Garrone et al., 2014), and can still be valorized for feeding animals or undergo recycling or recovery activities in a Circular Economy perspective. Unrecovered FW implies the wastage of resources used to produce, handle, transform, and distribute the products, creates unnecessary pressures on the environment, from local pollution to greenhouse gases (GHGs), and jeopardizes biodiversity and rural societies and economies (FAO, 2019). FW management is the subject of at least 2 Targets in the 2030 Agenda of the United Nations, under Sustainable Development Goal 12, that is, Target 12.3 ("Halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses, by 2030") and Target 12.5 ("Substantially reduce waste generation through prevention, reduction, recycling, and reuse by 2030") (Ishangulyyev et al., 2019; United Nations, 2015). An even greater concern is the paradoxical coexistence of high FW volumes with food poverty. Aside from the tragedy of undernutrition in low-income countries, food and nutrition insecurity is also present in high-income countries such as the United States (Coleman-Jensen et al., 2021) or EU-27 and the United Kingdom (FAO, 2021), and sharpens under crisis situations (FSIN and Global Network Against Food Crises, 2021).

F&V is a food category with one of the highest food loss rates (about 22% from post-harvest to distribution; (FAO, 2019). Intrinsic perishability and exposure to pests' attacks makes the management and distribution of these fresh products especially complicated (FAO, 2020). The analysis of horticultural FW and SF and the identification of possible prevention and valorization strategies is a priority in food systems because of the increasing world population and food demand, and F&V centrality for healthy and balanced diets (Villalobos et al., 2019). Nevertheless, literature on waste reduction in F&V supply chains is rather fragmented.

The literature review (Section 2) allows to pinpoint a major research gap and to set forward the first research question (RQ1): What are the main SF and FW causes in the different stages of F&V supply chain? Indeed different pieces of knowledge about SF and FW causes in the stages of F&V supply chains have already been offered, yet the literature results are sparse in terms of supply chain stages, types of root issues, phases of FWH adopted. To overcome this fragmentation, a Causes Framework (CF) is developed and used to organize and synthesize the literature results along the supply chain (Section 3). For each stage of the F&V supply chain it identifies the SF and FW causes with a greater prevalence, and the root issues underlying food waste.

A second RQ concerns the method through which CF can be applied to analyze the FW relevant problems in specific F&V chains (RQ2): (RQ2) How can the highest-priority SF and FW causes and root problems be found in a specific F&V supply chain? The CF utility is demonstrated by collecting and analyzing qualitative empirical evidence from a single case study, namely the Mantuan PGI pear supply chain in Italy, and discussing the case fit into the framework. The entire F&V supply chain is the unit of analysis, considering five stages (agricultural production, handling and storage, processing and packaging, distribution, retail). The choice of the case study is linked to the ESPERA project in which two authors are involved. To the best of the author's knowledge, this is the first study to explore the pear supply chain in Italy from the perspective of SF and FW generation, with the final aim of facilitating the decisions about where resources and efforts should be directed, both by public and private actors, to implement improvement actions for the prevention and reduction of food waste.

Nomenclature

CF	Causes Framework		
FAO	Food and Agriculture Organization	F&V	Fruit and vegetables
FW	Food Waste	PGI	Protected Geographical Indication
FWH	Food Waste Hierarchy	RQ	Research questions
		SF	Surplus food

2. Literature review

The main topic of the paper, namely the causes of SF and FW along the F&V supply chain, was the subject of a systematic literature search that made use of different combinations of keywords. Results were concentrated in journals of agriculture and food management and waste and environmental management. Also documents and reports published online by national and international associations such as FAO (Food and Agriculture Organization of the United Nations), WRAP - Waste & Resources Action Programme, BCFN-Barilla Center for Food & Nutrition) were browsed. Eventually over 30 publications were selected as especially relevant. A few of them helped in the first place to define the structure of the F&V supply chain and to choose the boundaries of the analysis. Taking as main references Verdouw et al. (2010), WRAP (2011), FAO (2011), Hodges et al. (2011), Villalobos et al. (2019) and Magalhães et al. (2020), the most suitable structure encompasses agricultural production (growing, harvesting), post-harvest handling and storage (washing, sorting, grading, temperature-controlled storage), post-harvest processing and packaging, post-harvest distribution, retail as shown in Figure 1.

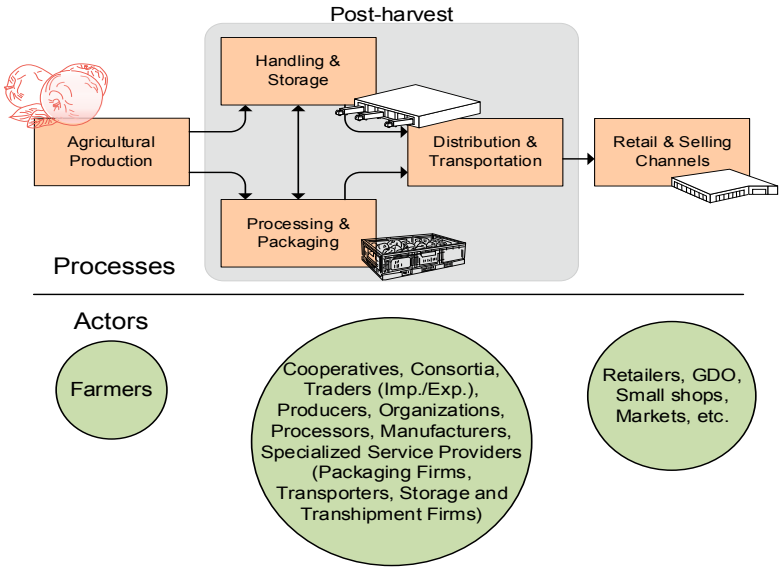

Fig. 1. F&V supply chain.

For each of the five stages of the F&V supply chain it was possible to list the causes of surplus food and food waste. For this reason, it was considered particularly important to first investigate the individual stages, going into the details of the specific operational process, the natural or external phenomena that influence activities and decisions, the quality standards required, but at the same time trying to understand the inter-relations between actors operating at different stages. Multiple problems that occur in the supply chain stages are at the origin of F&V surplus and waste. Notably, SF or FW materialize in one stage, but their generation causes might have roots in external events or in decisions and practices carried out in other stages of the supply chain (Raak et al., 2017). Here we are presenting them in their emergence stage, but intra-chain linkages are highlighted as well. For a better interpretation of the review, its focus on developed countries should be reminded. Indeed lower-income countries experience different SF and FW causes (FAO, 2011).

Agricultural production. SF and FW in cultivation and harvesting may be linked to natural trends that reduce the produce quantity and deteriorate its quality such as weather variability and extreme weather events or diseases, pests and contaminations (Beausang et al., 2017), and other mostly exogenous events such as recent regulations of pesticides motivated by health concerns (Priefer et al., 2016; Fernandez-Zamudio et al., 2020), poor communication by retailers (Beausang et al., 2017), changes in consumers' tastes related to trends such as ageing (Beausang et al., 2017), shocks in market demand (Johnson et al., 2018; Johnson et al., 2019), including low prices that do not cover harvesting and transportation costs or unavailability of buyers, which may result in products left in the fields.

However large SF and FW volumes are mainly endogenous to strategies and operational conducts of farmers and other food supply chain actors. The following issues are recognized by existing studies to play a large role in SF and FW generation: intentional overproduction especially in contract farming, generally as a response to inherent incidence of non-conformity to the cosmetic quality standards set by retailers and regulations (Plazzotta et al., 2017) or difficulties in sales forecast and demand planning (Beausang et al., 2017; Magalhães et al., 2020), risks of rejection for entire loads because of few unmarketable units (Johnson et al., 2019), especially for smaller farmers unable to find alternative buyers), poor operational performance such as product damage especially during mechanized harvest (Beausang et al., 2017) or transportation (Magalhães et al., 2020), inappropriate agronomic practices about irrigation and fertilizing or harvest scheduling (Villalobos et al., 2019); especially rapidly ripening products (Magalhães et al., 2020; Johnson et al., 2019).

Handling and storage. Products are generally handled and stored in facilities external to fields and managed by producers' organizations that take care of sorting and channeling to different markets (Plazzotta et al., 2017) and managing inventory levels restrictions related to perishability and starting the cold chain (Villalobos et al., 2019). The following conducts may generate SF and FW: excess of safety stocks also because of inaccurate forecasting (Mena et al., 2014); inappropriate maintenance of the cold-chain and lack of appropriate storage infrastructure, especially cold-chain equipment and facilities (Mena et al., 2014; Villalobos et al., 2019); inadequate storage and handling operations that result in mechanical and biochemical disruptions (Ertan et al., 2019; Magalhães et al., 2020; Fernandez-Zamudio et al., 2020); defective or ill-suited packaging (WRAP, 2011), use of reference dates with perishable products (Mena et al., 2014). Some production problems rooted elsewhere may come to surface in the present stage, as Figure 2 will highlight: defects determined by wrong operational practices and weather issues during production (Mena et al., 2014; Beausang et al., 2017), or by diseases pests and contaminations (Fernandez-Zamudio et al., 2020). It is at this stage that decisions to withdraw from markets because of non-conformity with retailers' quality specifications (Mena et al., 2014), pricing and promotions strategies (Villalobos et al., 2019), unavailable buyers at the ripening time (Gunders, 2012) are mostly made.

Packaging and processing. In this stage F&V products are further sorted and graded or transformed into secondary products with a longer shelf-life, such as for example dried fruit, juice, canned products or preserves. Processing activities entails many operational tasks (Verdouw et al., 2010), and may generate by-products such as recyclable compounds (Raak et al., 2017). Packaging of fresh produce or transformed products protects the content and facilitates handling and transportation tasks. Several SF and FW causes at this stage are originated by production, or handling and storage problems, and are shared by more than one stage, as Figure 2 will highlight. Additional issues have been studied as distinctive or slightly different. Problems emerging during the packaging and processing stage can be summarized as follows: excessive stock (Priefer et al., 2016); operational and logistical performances (Raak et al., 2017; Magalhães et al., 2020); non-conformity to qualitative requirements (Richter & Bokelmann, 2016; Raak et al., 2017) or residual shelf-life policy (Raak et al., 2017) of retailers and trading standards; contractual agreements with distributors and retailers about take-back and orders cancellation obligations (Richter & Bokelmann, 2016; Priefer et al., 2016); consumers attitude towards substandard F&V trimming (Richter & Bokelmann, 2016; Gunders, 2012).

Wholesale distribution. Wholesale trading and logistics is an understudied stage as far as FW and SF in F&V is concerned. Some problems and dynamics that have been already reviewed for upstream stage may have consequences in the present stage (Figure 2), such as non-conformity to quality specifications (Ghosh et al., 2017), also because of inadequate agronomic and harvesting decisions), and diseases, pests or contamination (Hodges et al., 2011; Ertan et al., 2019). Nevertheless, there are FW and SF causes that are unique to this stage or are studied from a special angle, such as the following issues: inadequate transportation management (Gunders, 2012; Ertan et al., 2019), distance travelled from logistic centers to points of sale (Mena et al., 2014), lack of appropriate storage and cold chain facilities (Priefer et al., 2016; Porat et al., 2012), oversupply practice (Gunders, 2012), poor operational performance (Hodges et al., 2011; Ertan et al., 2019) including temperature control, (Porat et al., 2012; Gunders, 2012), expiry of sell-by or best-before dates (Magalhães et al., 2020), lack of alternative buyers (Ghosh et al., 2017), take-back and orders cancellation contractual clauses (Eriksson et al., 2012).

Retail. At the retail stage so-called pre-store F&V waste, emerging at the entry point, is rejected yet additional SF and FW emerge in the store, and could have a local cause or be originated by problems occurring in the upstream stages, or even by consumer's practices and attitudes. A part of FW and SF is originated by decisions or problems

pertaining the same retail stage such as inadequate demand forecasting and ordering (Mattsson et al., 2018; Porat et al., 2012), and related excessive stock due to demand forecasting difficulties (Buzby et al., 2015), poor handling by store employees (Mattsson et al., 2018), defective packaging, technical malfunctioning or malpractices with the controlled temperature (Buzby et al., 2015), inefficient management of shelves and displayers (Mattsson et al., 2018) non-conformity to own quality requirements and grading (Lebersorger & Schneider, 2014; Buzby et al., 2015). As far as upstream SF and FW origins are concerned, responsibility for F&V deterioration may go back to pests, diseases, contamination in upper stages (Buzby et al., 2015), even though dented, overripe, moldy, withered or moist F&V are regular form of deterioration with unsold products sold in bulk (Lebersorger & Schneider, 2014). Symmetrically, promotion management and pricing by retailers can stimulate overproduction or excess stocks in upstream stages or excess purchases in households (Mena et al., 2014). Finally, the problems related to consumers are intolerance of esthetically-imperfect products (Buzby et al., 2015), inadequate handling at selection time (Buzby et al., 2015; Mattsson et al., 2018), taste variations (Mena et al., 2014)

A SF and FW cause that affects all the stages is poor coordination and communication with supply chain actors of other stages (Buzby et al., 2015; Mena et al., 2014; Pellegrini et al., 2020).

The literature review shows the existence of a few research gaps. Most existing studies focus on single products, and single deterioration mechanisms. Even articles that explore the SF and FW causes for F&V in general hardly ever investigate more than one supply chain stage (for example, Eriksson et al. (2012), Beausang et al. (2017), Mattsson et al. (2018), and Johnson et al. (2019)), even though FW may materialize in one stage and have roots in decisions and activities taken at a different stage as exemplified in many points of the literature review. Secondly, a few studies focus on few causes of SF generation and its degradation into FW, and proceed with food waste quantification, without exploring the possible presence of a broader set of critical points and root causes for the focal case (WRAP, 2011; Porat et al., 2012; FAO, 2019). Finally, SF and FW causes along the F&V supply chain are likely to have different degrees of significance as suggested by the same literature results, but they are not systematically prioritized.

Consistently with the gaps, the RQs guiding the research are two.

(RQ1) What are the main SF and FW causes in the different stages of F&V supply chain?

(RQ2) How can the highest-priority SF and FW cause and root problems be identified in a specific F&V supply chain using CF?

Table 1. SF and FW Causes Framework for F&V supply chains.
Note. High priority: dark shaded √ , Medium priority: light shaded √ . Low priority: unshaded √ .

MACRO-CATEGORIES		CAUSES OF SURPLUS FOOD AND FOOD WASTE	FSC STAGE				
			Agricultural Production	Handling Storage	Processing and Packaging	Distribution	Retail
Quality standards	1	Non-conformity to quality specifications	✓	✓	✓	✓	✓
Supply chain	2	Lack of coordination and information sharing	✓	✓	✓	✓	✓
Natural Causes	3	Product quality deterioration due to diseases, pest or contamination	✓	✓	✓	✓	✓
Operational process	4	Poor operational performance	✓	✓	✓	✓	✓
Supply chain	5	Overproduction; oversupply; excessive stock	✓	✓	✓	✓	✓
Quality standards	6	Short product shelf-life; near expiry products	✓	✓	✓	✓	✓
Operational process	7	Lack of appropriate storage facilities and cold chain facilities		✓	✓	✓	✓
Operational process	8	Inadequate or defective packaging		✓	✓	✓	✓
Supply chain	9	Inadequate demand forecastig; unpredictable orders	✓	✓	✓	✓	✓
Operational process	10	Storage at wrong temperatures		✓	✓	✓	✓
Operational process	11	Inadequate transportation management	✓	✓	✓	✓	
Operational process	12	Inadequate agronomic practices; inadequate harvest scheduling	✓	✓	✓	✓	
Natural Causes	13	Weather variability - extreme weather	✓	✓			
Consumers	14	Consumer education on food losses; consumer intolerance of substandard			✓		✓
Supply chain	15	Not-harvested products due to unprofitable market prices	✓				
Operational process	16	Transportation at wrong temperatures				✓	
Supply chain	17	Pricing strategies and promotions management	✓	✓	✓		✓
Supply chain	18	Buyer availability	✓	✓		✓	✓
Supply chain	19	Take back agreements and orders cancellation			✓	✓	
Operational process	20	Inadequate inventory and storage management		✓	✓		
Consumers	21	Changing consumer tastes and demand over years	✓	✓	✓	✓	✓
Supply chain	22	Risk of rejection	✓				
Operational process	23	Distance travelled				✓	
Consumers	24	Inadequate handling by consumers					✓
Operational process	25	Inefficient in-store management					✓
Operational process	26	Impossibility of repacking if one item becomes diseased or out of standard					✓
Operational process	27	Trimming			✓		

3. Causes Framework

In order to address RQ1, the results illustrated in the literature review are summarized in the CF of Table 1. The CF displays the SF and FW causes that affect one or more F&V supply chain stages, grading the degree of influence exerted (see the note). The first column shows the macro-category to which the cause belongs, namely the fundamental waste generation "root" problem underlying the emergence of SF and FW in either stage.

The literature review yields 27 different causes. A single SF and FW cause may emerge in one or more of the 5 F&V stages, yet it might be originated by external events, or decisions or activities undertaken in only one of the stages or paradoxically in a separated stage, regardless of where it materializes. The CF reports the causes without distinguishing them by product (supply chain).

Secondly, the SF and FW causes analyzed by the literature are grouped into 5 root categories (macro-categories, first column). Two problems are mainly external to the supply chain, namely Natural causes, and Consumers attitudes and behaviors. Other 3 fundamental problems have to do with conducts and decisions undertaken mainly within the F&V supply chain, namely poor Operational processes in the same stage, Quality standards generally dictated by retailers, interactions with other Supply chain actors.

Finally, since RQ1 aims to investigate the causes that have a major SF and FW impact, it was decided to prioritize for each stage the causes that were indicated as relevant in that stage by a relatively higher number of studies. More in detail, the ABC classification technique was adopted to assign a priority to the identified causes, and in particular the marginal increase method. To obtain a score for each cause, the number of references mentioning that cause for the specific stage multiplied by one are added to the number of references citing that specific cause as relevant factor generating SF and FW in that specific stage multiplied by 0.5. The average score of the causes for each stage was computed. In class A, all causes with a score higher than the average score were included. Class B includes the causes with a score higher than the average score calculated only for the remaining causes, not already included in class A. Finally, in class C all the remaining causes were included. SpThe "high priority" class (dark shade in Figure 2) includes the causes to which the organizations of the stage should pay greater attention and propose and implement improvement actions. The "low priority" class (tick without any shade in Figure 2) includes causes that in principle are less urgent because the extant literature does not indicate them as significant. Finally, Table 2 depicts the list of 27 identified SF and FW causes along the F&V supply chain with the main references found in literature. Moreover, for each SF and FW cause the F&V product types investigated in the main references are also mentioned.

Table 2. SF and FW Causes Framework in F&V supply chains with main references identified in literature.

	CAUSES OF SURPLUS FOOD AND FOOD WASTE	MAIN REFERENCES	F&V PRODUCTS INVESTIGATED IN MAIN REFERENCES
1	Non-conformity to quality specifications	Beausang et al., (2017); Beretta et al., (2013); Buzby et al., (2015); De Steur et al., (2016); Eriksson et al., (2012); Ertan et al., 2019); FAO, 2011); Fernandez-Zamudio et al., (2020); Ghosh et al., (2017); Gunders, (2012); Hodges et al., (2011); Ishangulyyev et al., (2019); Johnson et al., (2018); Johnson et al., (2019); Joensuu et al., (2020); Kitinoja et al., (2018); Lebersorger & Schneider, (2014); Magalhães et al., (2020); Mattsson et al., (2018); Mena et al., (2014); Plazzotta et al., (2017); Priefer et al., (2016); Raak et al., (2017); Richter & Bokelmann, (2016); WRAP, (2011); WRAP, (2017).	Apples, avocadoes, apricots, broccoli, brussel sprouts, blueberries, bananas, bell pepper, citrus, cucumber, cabbage, carrots, cantaloupe, cranberries, cherries, dates, fig, grapefruit, grapes, honeydew, kiwi, limes, lemons, lettuce, leeks, mandarins, mangoes, melons, mushrooms, oranges, onions, pomegranate, persimmon, peaches, plums, pears, potatoes, papayas, pineapples, plantains, raspberries, summer squash, strawberries, sweet corn, sweet pepper, sweetpotatoes, tomatoes, tamarillo, tangerines, watermelon, winter squash.
2	Lack of coordination and information sharing	Beausang et al., (2017); Beretta et al., (2013); Buzby et al., (2015); Eriksson et al., (2012); Ertan et al., (2019); FAO, (2011); Ghosh et al., (2017); Ishangulyyev et al., (2019); Johnson et al., (2019); Kitinoja et al., (2018); Magalhães et al., (2020); Mena et al., (2014); Priefer et al., (2016); Pellegrini et al., (2020); Richter &	Apples, avocadoes, apricots, broccoli, brussel sprouts, blueberries, bananas, citrus, carrots, cantaloupe, cranberries, cherries, dates, fig, grapefruit, grapes, honeydew, kiwi, limes, lemons, lettuce, leeks, mandarins, mangoes, oranges, onions, peaches, plums, pears, potatoes, papayas, pineapples, plantains, raspberries, strawberries, sweet pepper, sweetpotatoes, tomatoes, tamarillo, tangerines, watermelon.

		Bokelmann, (2016); Villalobos et al., (2019); WRAP, (2011).	
3	Product quality deterioration due to diseases, pest or contamination	Beausang et al., (2017); (Beretta et al., (2013); Buzby et al., (2015); Eriksson et al., (2012); Ertan et al., (2019); FAO, (2011); Fernandez-Zamudio et al., (2020); Gunders, (2012); Hodges et al., (2011); Ishangulyyev et al., (2019); Johnson et al., (2019); Joensuu et al., (2020); Kitinoja et al., (2018); Lebersorger & Schneider, (2014); Magalhães et al., (2020); Mattsson et al., (2018); Mena et al., (2014); Priefer et al., (2016); Richter & Bokelmann, (2016); Raak et al., (2017); WRAP, (2011); WRAP, (2017).	Apples, avocadoes, apricots, broccoli, brussel sprouts, blueberries, bananas, carrots, cantaloupe, cranberries, cherries, dates, fig, grapefruit, grapes, honeydew, kiwi, limes, lemons, lettuce, leeks, mandarins, mangoes, oranges, onions, persimmon, peaches, plums, pears, potatoes, papayas, pineapples, plantains, raspberries, strawberries, sweet pepper, sweetpotatoes, tomatoes, tamarillo, tangerines, watermelon.
4	Poor operational performance	Beausang et al., (2017); Beretta et al., (2013); Buzby et al., (2015); De Steur et al., (2016); Ertan et al., (2019); FAO, (2011); Fernandez-Zamudio et al., (2020); Gunders, (2012); Hodges et al., (2011); Ishangulyyev et al., (2019); Johnson et al., (2019); Joensuu et al., (2020); Magalhães et al., (2020); Mena et al., (2014); Mattsson et al., (2018); Priefer et al., (2016); Plazzotta et al., (2017); Raak et al., (2017); WRAP, (2011).	Apples, avocadoes, apricots, broccoli, brussel sprouts, blueberries, bananas, citrus, cabbage, carrots, cantaloupe, cranberries, cherries, dates, fig, grapefruit, grapes, honeydew, kiwi, limes, lemons, lettuce, leeks, mandarins, mangoes, melons, mushrooms, onions, oranges, pomegranate, persimmon, plantains, peaches, plums, pears, potatoes, papayas, pineapples, raspberries, sweetpotatoes, strawberries, tomatoes, tangerines, watermelon.
5	Overproduction; oversupply; excessive stock	Beretta et al., (2013); Buzby et al., (2015); FAO, (2011); Ghosh et al., (2017); Gunders, (2012); Hodges et al., (2011); Ishangulyyev et al., (2019); Joensuu et al., (2020); Magalhães et al., (2020); Mena et al., (2014); Plazzotta et al., (2017); Priefer et al., (2016); Porat et al., (2012); Richter & Bokelmann, (2016); WRAP, (2017).	Apples, avocadoes, apricots, broccoli, blueberries, bananas, citrus, cantaloupe, cranberries, cherries, cabbage, carrots, dates, grapefruit, grapes, honeydew, kiwi, limes, lemons, lettuce, mandarins, mangoes, melons, mushrooms, onions, oranges, pomegranate, plantains, papayas, pineapples, potatoes, peaches, plums, pears, raspberries, strawberries, sweetpotatoes, tomatoes, tangerines, watermelon.
6	Short product shelf-life; near expiry products	Beausang et al., (2017); Beretta et al., (2013); Buzby et al., (2015); Ertan et al., (2019); Eriksson et al., (2012); FAO, (2011); Gunders, (2012); Ishangulyyev et al., (2019); Lebersorger & Schneider, (2014); Magalhães et al., (2020); Mattsson et al., (2018); Mena et al., (2014); Priefer et al., (2016); Porat et al., (2012); Raak et al., (2017); Villalobos et al., (2019).	Apples, avocadoes, apricots, broccoli, brussel sprouts, blueberries, bananas, citrus, carrots, cantaloupe, cranberries, cherries, cucumbers, cauliflower, dates, fig, grapefruit, grapes, honeydew, kiwi, limes, lemons, lettuce, leeks, mandarins, mangoes, oranges, onions, peaches, plums, pears, potatoes, papayas, pineapples, plantains, raspberries, strawberries, sweet pepper, sweetpotatoes, tomatoes, tamarillo, tangerines, watermelon.
7	Lack of appropriate storage facilities and cold chain facilities	Beausang et al., (2017); Ertan et al., (2019); Gunders, (2012); Ishangulyyev et al., (2019); Magalhães et al., (2020); Mena et al., (2014); Priefer et al., (2016); Porat et al., (2012); Villalobos et al., (2019).	Apples, avocadoes, bananas, broccoli, brussel sprouts, cucumbers, cauliflowers, citrus, carrots, lettuce, leeks, onions, potatoes, raspberries, strawberries, tomatoes.
8	Inadequate or defective packaging	Buzby et al., (2015); FAO, (2011); Gunders, (2012); Ishangulyyev et al., (2019); Magalhães et al., (2020); Mena et al., (2014); Priefer et al., (2016); WRAP, (2011).	Apples, avocadoes, apricots, broccoli, blueberries, bananas, citrus, cantaloupe, cranberries, cherries, dates, grapefruit, grapes, honeydew, kiwi, limes, lemons, lettuce, mandarins, mangoes, onions, oranges, plantains, papayas, pineapple, potatoes, peaches, plums, pears, raspberries, strawberries, sweetpotatoes, tomatoes, tangerines, watermelon.
9	Inadequate demand forecastig; unpredictable orders	Beausang et al., (2017); Beretta et al., (2013); Buzby et al., (2015); Gunders, (2012); Ishangulyyev et al., (2019); Kitinoja et al., (2018); Mattsson et al., (2018); Magalhães et al., (2020); Mena et al., (2014); Priefer et al., (2016); Porat et al., (2012); Richter & Bokelmann, (2016); WRAP, (2017); WRAP, (2011).	Apples, avocadoes, apricots, broccoli, brussel sprouts, blueberries, bananas, cauliflower, cucumbers, citrus, carrots, cantaloupe, cranberries, cherries, grapefruit, grapes, honeydew, kiwi, limes, lemons, lettuce, leeks, mangoes, onions, oranges, peaches, plums, pears, potatoes, papayas, pineapples, raspberries, strawberries, tomatoes, tangerines, watermelon.
10	Storage at wrong temperatures	Buzby et al., (2015); Ertan et al., (2019); Gunders, (2012); Magalhães et al., (2020); Mena et al., (2014); Porat et al., (2012); Villalobos et al., (2019); WRAP, (2011).	Apples, avocadoes, apricots, broccoli, blueberries, bananas, cucumbers, cauliflower, citrus, cantaloupe, cranberries, cherries, fig, grapefruit, grapes, honeydew, kiwi, lettuce, limes, lemons, mangoes, onions, oranges, papayas, pineapple,

			potatoes, peaches, plums, pears, raspberries, strawberries, tangerines, tomatoes, watermelon.
11	Inadequate transportation management	Beretta et al., (2013); Buzby et al., (2015); Ertan et al., (2019); Gunders, (2012); Ishangulyyev et al., (2019); Lebersorger & Schneider, (2014); Magalhães et al., (2020); Mena et al., (2014).	Apples, avocadoes, apricots, broccoli, blueberries, bananas, cantaloupe, cranberries, cherries, citrus, fig, grapefruit, grapes, honeydew, kiwi, lettuce, limes, lemons, mangoes, oranges, onions, papayas, pineapple, potatoes, peaches, plums, pears, raspberries, strawberries, tangerines, tomatoes, watermelon.
12	Inadequate agronomic practices; inadequate harvest scheduling	Beausang et al., (2017); Fernandez-Zamudio et al., (2020); Ghosh et al., (2017); Ishangulyyev et al., (2019); Johnson et al., (2018); Johnson et al., (2019); Kitinoja et al., (2018); Mena et al., (2014); Villalobos et al., (2019); WRAP, (2011); WRAP, (2017).	Apples, avocadoes, broccoli, bananas, bell pepper, brussel sprouts, citrus, cucumber, cabbage, carrots, cherries, lettuce, leeks, onions, potatoes, persimmon, raspberries, sweet corn, summer squash, strawberries, sweetpotatoes, tomatoes, winter squash, watermelon.
13	Weather variability - extreme weather	Beausang et al., (2017); Beretta et al., (2013); Fernandez-Zamudio et al., (2020); FAO, (2011); Gunders, (2012); Ishangulyyev et al., (2019); Joensuu et al., (2020); Johnson et al., (2019); Kitinoja et al., (2018); Magalhães et al., (2020); Mena et al., (2014); WRAP, (2011); WRAP, (2017).	Apples, avocadoes, bananas, broccoli, brussel sprouts, berries, citrus, carrots, cabbage, dates, lettuce, leeks, onions, persimmon, potatoes, raspberies, strawberries, tomatoes.
14	Consumer education on food losses; consumer intolerance of substandard	Beretta et al., (2013); Buzby et al., (2015); Eriksson et al., (2012); FAO, (2011); Gunders, (2012); Hodges et al., (2011); Ishangulyyev et al., (2019); Mena et al., (2014); Raak et al., (2017); Richter & Bokelmann, (2016); WRAP, (2011).	Apples, avocadoes, apricots, blueberries, bananas, cantaloupe, cranberries, cherries, dates, grapefruit, grapes, honeydew, kiwi, limes, lemons, mandarins, mangoes, onions, oranges, plantains, papayas, pineapple, potatoes, peaches, plums, pears, strawberries, sweetpotatoes, tangerines, watermelon.
15	Not-harvested products due to unprofitable market prices	Beretta et al., (2013); Gunders, (2012); Ishangulyyev et al., (2019); Johnson et al., (2018); Johnson et al., (2019); Kitinoja et al., (2018); Priefer et al., (2016).	Apples, bananas, berries, bell pepper, cabbage, cucumber, potatoes, strawberries, sweet corn, sweetpotatoes, summer squash, tomatoes, winter squash, watermelon.
16	Transportation at wrong temperatures	Ertan et al., (2019); Gunders, (2012); Ishangulyyev et al., (2019); Mena et al., (2014); Villalobos et al., (2019); WRAP, (2011).	Apples, avocadoes, broccoli, bananas, citrus, fig, lettuce, onions, potatoes, raspberries, strawberries, tomatoes.
17	Pricing strategies and promotions management	Beausang et al., (2017); Buzby et al., (2015); Gunders, (2012); Johnson et al., (2019); Magalhães et al., (2020); Mena et al., (2014); Villalobos et al., (2019); WRAP, (2011).	Apples, avocadoes, apricots, broccoli, brussel sprouts, blueberries, bananas, carrots, cantaloupe, cranberries, cherries, grapefruit, grapes, honeydew, kiwi, limes, lemons, lettuce, leeks, mangoes, oranges, peaches, plums, pears, potatoes, papayas, pineapples, strawberries, tangerines, watermelon.
18	Buyer availability	Gunders, (2012); Ghosh et al., (2017); Kitinoja et al., (2018); Johnson et al., (2018); Johnson et al., (2019); Joensuu et al., (2020); WRAP, (2017).	Apples, bell pepper, carrots, cabbage, cucumber, cherries, onions, potatoes, strawberries, summer squash, sweet corn, sweetpotato, tomatoes, watermelon, winter squash.
19	Take back agreements and orders cancellation	Eriksson et al., (2012); Gunders, (2012); Mattsson et al., (2018); Priefer et al., (2016); Richter & Bokelmann, (2016).	Apples, banana, carrot, grape, lettuce, orange, papaya, pear, potatoes, sweet pepper, strawberries, tomato, tamarillo.
20	Inadequate inventory and storage management	Beausang et al., (2017); Mena et al., (2014); WRAP, (2011).	Apples, bananas, broccoli, brussel sprouts, citrus, carrots, lettuce, leeks, onions, potatoes, raspberries, strawberries, tomatoes.
21	Changing consumer tastes and demand over years	Beausang et al., (2017); Beretta et al., (2013); Mena et al., (2014).	Apples, avocadoes, bananas, broccoli, brussel sprouts, berries, citrus, carrots, lettuce, leeks, onions, potatoes, raspberries, strawberries, tomatoes.
22	Risk of rejection	Johnson et al., (2018); Johnson et al., (2019).	Bell pepper, cucumber, cabbage, summer squash, sweetpotatoes, sweet corn, tomatoes, watermelon, winter squash.
23	Distance travelled	(Mena et al., (2014).	Apples, avocadoes, broccoli, bananas, citrus, lettuce, onions, potatoes, raspberries, strawberries, tomatoes.
24	Inadequate handling by consumers	Buzby et al., (2015); Gunders, (2012); Mena et al., (2014); Mattsson et al., (2018); WRAP, (2011).	Apples, avocadoes, apricots, blueberries, broccoli, bananas, citrus, cantaloupe, cranberries, cherries, grapefruit, grapes, honeydew, kiwi, lettuce, limes, lemons, mangoes, onions, oranges, papayas, pineapple, potatoes, peaches, plums, pears, raspberries, strawberries, tomatoes, tangerines, watermelon.

25	Inefficient in-store management	Buzby et al., (2015); Magalhães et al., (2020); Mattsson et al., (2018); Mena et al., (2014); WRAP, (2011).	Apples, avocadoes, apricots, blueberries, bananas, citrus, cantaloupe, cranberries, cherries, grapefruit, grapes, honeydew, kiwi, lettuce, limes, lemons, mangoes, onions, oranges, papayas, pineapple, potatoes, peaches, plums, pears, raspberries, strawberries, tomatoes, tangerines, watermelon.
26	Impossibility of repacking if one item becomes diseased or out of standard	Buzby et al., (2015); Lebersorger & Schneider, (2014); Mattsson et al., (2018); Mena et al., (2014).	Apples, avocadoes, apricots, broccoli, blueberries, bananas, citrus, cantaloupe, cranberries, cherries, grapefruit, grapes, honeydew, kiwi, lettuce, limes, lemons, mangoes, onions, oranges, papayas, pineapple, potatoes, peaches, plums, pears, raspberries, strawberries, tangerines, tomatoes, watermelon.
27	Trimming	FAO, (2011); Gunders, (2012).	Apples, bananas, dates, grapefruit, grapes, lemons, limes, mandarins, onions, oranges, plantains, pineapples, potatoes, sweetpotatoes, strawberries, tomatoes.

4. CF Application in a PGI pear supply chain

The second RQ asks to discover the SF and FW causes in a specific F&V chain and to understand their priority and roots, by making use of the CF as a lens.

4.1 Method: case study of a F&V supply chain

The generation of SF and FW entails complex dynamics, and unfolds within and between different F&V supply chain actors, and at the interfaces with the natural environment and consumers behaviors. RQ2 requires to understand how SF and FW are currently generated in a specific supply chain, a context that is not manipulable by the researchers, and therefore it offers conditions suitable for application of case study methodology. A single case study with a holistic approach is conducted, with the purpose of refining the CF and demonstrating its application (RQ2).

First, a specific supply chain has been selected with the purpose of being able to interview players from all the stages, adopting the entire supply chain perspective. The pear supply chain in Italy and specifically a PGI (Protected Geographical Indication) pear that grows in Mantua, a North Italy province, has been chosen because it is the subject of a project (Espera) of which the authors are members (see the Acknowledgments). Since the Mantuan PGI pear is produced in a small area, an extension of case boundaries to other neighboring PGI pear supply chains (located in Emilia Romagna Region) was accepted as consistent with the objective of the research. Contacts were initially taken with enterprises that are part of the project network and after that enlarged through contacts established in other projects. The sample is made up by 9 participants belonging to 6 enterprises. They have been reached via 7 interviews. The main characteristics of interviewees are summarized, stage by stage, in Table 3.

Second, thanks to secondary information retrieved through the analysis of online reports and website articles, it was possible to understand the context of the Mantuan PGI pear. A questionnaire has been designed with questions reflecting the CF for each stage, and primary information has been obtained through semi-structured interviews. Particular attention was given not to communicate the cause sign (SF or FW increase / decrease) and priority as reported in the CF, in order not to alter the spontaneous response of the informant. Deviations and additions were expected, also because the literature summarized by the CF refers to a plurality of F&V products, as illustrated in Table 2.

Finally, the interviews were performed between November 2020 and February 2021 through video calls (in 1 case out of 7, phone call). They were led by two researchers and took approximately one hour each. The coding of transcribed texts made possible the capture of the large set of information necessary to make a direct comparison between case study and literature findings. A deductive approach leveraging the CF structure was used to identify categories and codes.

Table 3. Sample of interviewees.

Enterprise	Supply chain stage	Number of interviews	Number of interviewees	Job titles of the interviewees

Farmer	Agricultural production	1	1	Agricultural Entrepreneur
Cooperative	Handling and storage	1	2	General Director President
Association of producers' organizations	Handling and storage	1	1	General Director
Transformer	Processing and packaging	1	2	R&D Director Agricultural Services Director
Retailer	Distribution and Retail	2	1	Quality Manager
			1	Purchasing Manager
Retailer	Retail	1	1	Point of sales Director

4.2 Case study results

As Tables 4-8 shows, some of the CF causes were not mentioned by the interviewees or are not considered a problem in the specific supply chain, while a few SF and FW causes not included in the CF were indicated as relevant. Some causes were mentioned in slightly different ways compared to the literature, or with a different priority. Through an analysis of interviewees' words close to that employed with literature (Figure 2) priority classes were defined, suggesting their criticality on SF and FW generation and urgency of introducing corrective actions.

Table 4. SF and FW causes - Agriculture production

Only included in the CF	Included in CF (*) and observed in pears supply chain (°)	Only observed in pears supply chain (other stages in CF, or newly introduced)
5 Overproduction; oversupply; excessive stock	1 Non-conformity to quality specifications (*°)	*28 Restriction in number of residues*
15 Not-harvested products due to unprofitable market prices	2 Lack of coordination and information sharing (*°)	
	3 Product quality deterioration due to diseases, pest or contamination (*°)	
	13 Weather variability – extreme weather (*°)	
	4 Poor operational performance (*)	
	12 Inadequate agronomic practices; inadequate harvest scheduling (*)	

Note: (*°) both literature and case study cite the cause as a priority; (*) cited as a priority only in the CF; (°) cited as a priority only in the case study; in *italics* if the cause was either reviewed or newly introduced based on the findings of the cause study relatively to the original CF framework derived from literature.

Table 5. SF and FW causes – Post-harvest handling and storage

Only included in the CF	Included in CF and observed in pears supply chain	Only observed in pears supply chain (other stages in CF, or newly introduced)
4 Poor operational performance	1 Non-conformity to quality specifications (*°)	14 Consumer education on food losses; consumer intolerance of substandard food
	2 Lack of coordination and information sharing (*°)	*28 Restriction in number of residues*
	3 Product quality deterioration due to diseases, pest or	*29 Fragmented supply*

	contamination (*°)	
	6 Short product shelf life; near expiry products (*)	
	7 Lack of appropriate storage facilities and cold chain facilities (*)	

Note: (*°) both literature and case study cite the cause as a priority; (*) cited as a priority only in the CF; (°) cited as a priority only in the case study; in *italics* if the cause was either reviewed or newly introduced based on the findings of the cause study relatively to the original CF framework derived from literature.

Table 6. SF and FW causes – Processing and packaging

Only included in the CF	Included in CF and observed in pears supply chain	Only observed in pears supply chain (other stages in CF, or newly introduced)
8 Inadequate or defective packaging	1 Non-conformity to quality specifications (*°)	
	2 Lack of coordination and information sharing (*)	
	3 Product quality deterioration due to diseases, pest or contamination (*)	
	4 Poor operational performance (*)	
	5 Overproduction; oversupply; excessive stock (*)	

Note: (*°) both literature and case study cite the cause as a priority; (*) cited as a priority only in the CF; (°) cited as a priority only in the case study; in *italics* if the cause was either reviewed or newly introduced based on the findings of the cause study relatively to the original CF framework derived from literature.

Table 7. SF and FW causes – Post-harvest Distribution

Only included in the CF	Included in CF and observed in pears supply chain	Only observed in pears supply chain (other stages in CF, or newly introduced)
3 Product quality deterioration due to diseases, pest or contamination	1 Non-conformity to quality specifications (*°)	*30 Inadequate ripening and conservation of the product*
7 Lack of appropriate storage facilities and cold chain facilities	2 Lack of coordination and information sharing (*°)	
16 Transportation at wrong temperatures	8 Inadequate or *missing* packaging (*°)	
	6 Short product shelf life; near expiry products (°)	
	11 Inadequate transportation management (*)	
	12 Inadequate agronomic practices; inadequate harvest scheduling (°)	

Note: (*°) both literature and case study cite the cause as a priority; (*) cited as a priority only in the CF; (°) cited as a priority only in the case study; in *italics* if the cause was either reviewed or newly introduced based on the findings of the cause study relatively to the original CF framework derived from literature.

Table 8. SF and FW causes – Retail

Only included in the CF	Included in CF and observed in pears supply chain	Only observed in pears supply chain (other stages in CF, or newly introduced)
	1 Non-conformity to quality specifications (*°)	24 Inadequate agronomic practices; inadequate harvest scheduling
	2 Lack of coordination and information sharing (*°)	*30 Inadequate ripening and conservation of the product*

6 Short product shelf life; near expiry products (*°)	
14 Consumer education on food losses; consumer intolerance of substandard food (*°)	
5 Overproduction; oversupply; excessive stock (*)	
8 Inadequate or *missing* packaging (°)	
9 Inadequate demand forecasting; unpredictable orders (*)	
24 Inadequate handling by consumers (°)	

Note: (*°) both literature and case study cite the cause as a priority; (*) cited as a priority only in the CF; (°) cited as a priority only in the case study; in *italics* if the cause was either reviewed or newly introduced based on the findings of the cause study relatively to the original CF framework derived from literature.

5. Conclusions

The results obtained from CF development allows to answer the question about major SF and FW causes in the different stages of F&V supply chain, their priority, and roots. Secondly, the paper also shows the steps to apply CF in a specific F&V supply chain and discover the pertaining causes. Emphasis is put on the fundamental problems that unleash the most influential surplus and waste causes, from outside the supply chain (natural causes, consumers attitudes and behaviors) or within the supply chain yet not necessarily in the focal stage (poor operational processes, quality standards set by retailers, interactions with other supply chain actors).

The findings have implications for decision-makers of agri-food enterprises and public sector. They are presented with an instrument that supports them in the identification of high-priority SF and FW causes at each stage of the supply chain, accompanying them to elaborate and implement the necessary responses. The application to the pears supply chain offers them an example of the process to follow in the analysis of the causes.

A current limitation of the paper, especially in the perspective of applying the FWH, is the lack of a clear distinction between causes that generate reusable SF and those that create FW to manage through recycling and recovery. In spite of it, the study enriches the literature, by integrating sparse pieces of knowledge about SF and FW causes in a compact Causes Framework that shows in a comprehensive way the most critical sources of surplus and waste in single supply chain stages, and links them with fundamental root problems. In this way the study may spur future research, which can focus on hotspots and related improvement actions. Finally additional interviews could be conducted, including for instance the perspective of the logistic provider, to further enrich and corroborate the Causes Framework.

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