A system-wide interdisciplinary conceptual framework for food loss and waste mitigation strategies in the supply chain

Abstract:

The issues of food loss and waste (FLW) in the global supply chains have recently attracted attention. However, the causes of and strategies for mitigating FLW at different stages of the supply chains remain under researched. Our research aims to address these gaps in knowledge in a three-fold way: i) we identified the key causes (through root-cause analysis) of FLW in the supply chain of developed and less developed countries; ii) we systematically classified measures and policies that have been implemented to mitigate FLW; and iii) we developed an interdisciplinary conceptual framework for waste utilisation practices that can contribute towards the triple bottom-line in food systems. A root-cause analysis was performed and mitigation strategies identified by systematically analysing and synthesising the research published over the past 20 years (1998 to 2018) in the areas of FLW in the supply chain. We propose a conceptual model for the prevention of FLW utilising a systems approach through the concept of a circular economy. Since the agri-food sector is largely interdisciplinary, in our proposed model, we have also demonstrated a method of integrating contributions from multiple disciplines towards achieving total depollution (zero waste) in the supply chain.

Keyword: Food loss, food waste, root cause, supply chain, mitigation, circular economy

Introduction

Over the last decade, food loss and waste (FLW) in terms of quality and quantity has become a major concern from both an environmental and a social point of view (Secondi et al., 2015). According to the United Nations, an estimated one-third of all food is lost or wasted worldwide leaving 800 million people undernourished (Gustavsson et al., 2011). In 2015, a challenge was taken up to achieve the Sustainable Development Goals (SDG) established by the United Nations towards eradicating hunger by 2030. As the world population continues to grow, simply increasing food production is not the solution, as it comes with a high cost, i.e., by putting pressure on the scarce natural resources of land, water, and biodiversity. Therefore, a system-wide approach and effort is required urgently, which can add value across the supply chain by retaining nutritional benefits in the context of minimising FLW from the production to the consumption phase (Hawkes & Ruel, 2012). Given that the different processes (e.g., production, distribution/logistics, and consumption) in the agri-food supply chain originate from different disciplines, an integrated system-wide interdisciplinary approach is needed to give a holistic understanding of FLW across the supply chain.

Different definitions of food loss and food waste are reported in the scientific literature, creating problems for comparative studies and limiting the scope of amalgamation of their results into a common strategy for reducing food loss (Williams et al., 2015). The UN Food and Agriculture Organisation (FAO) was the first authorising body that tried to harmonise and systematise the definitions related to food loss and food waste through a definitional framework of food loss (FAO, 2014a). Food losses refer to the decrease in edible food mass throughout the part of the supply chain grown explicitly for human consumption. Food losses mainly occur at the upstream supply chain such as during production, post-harvesting and processing. The main drivers for food loss are infrastructure limitations, climate and environmental factors, and grading for quality or safety standards (Dora, 2019). In contrast, food waste occurs when food that was originally produced for human consumption is either removed wastefully or is not consumed by humans. This includes food that was spoiled prior to its disposal and food that was still edible when thrown away (Thyberg & Tonjes, 2016). Food waste mainly occurs in the later stages of the supply chain (retail and consumer end) due to strict specifications for quality or safety standards (Parfitt et al., 2010).

Food waste generation can have several impacts on the three of the four pillars of sustainability, namely, economic, social, and environmental sustainability (Vandermeersch et al.,

2014), leaving aside the moral dimension. In addition, FLW is responsible for high levels of greenhouse gas emissions, food insecurity, and economic loss (Stancu et al., 2016). In the coming years, SDG will strive to ensure the sustainable reduction of waste generation through prevention/reduction, recycling, and reuse by applying a systematic approach and promoting cooperation among the actors operating in the supply chain. Within this context, we are starting to see an alignment with the principles of a circular economy. According to Matharu et al. (2016), food supply chain (FSC) waste is a unique bio resource that may be exploited (valorised) for high value-added chemicals, functional materials, and bioenergy. The FAO's High-Level Panel of Experts on Food Security and Nutrition (HLPE, 2014) concluded that valorisation approaches to food waste and by-products streams can be regarded as a sensible solution to reduce waste in supply chains at the meso- and macro-levels of the global food system.

As mentioned earlier, food can be lost or wasted at any stage of the supply chain. In less developed countries (LDCs), especially in densely populated regions like South and Southeast Asia, where rice is the dominant crop, food loss occurs mainly in the upstream stages of the food supply chain, i.e., in the production, postharvest handling, processing, and storage due to a lack of financial, technical, and managerial resources (Gustavsson et al., 2011; Dora et al., 2019). In contrast, in developed countries (DCs), losses usually occur in the downstream stages of the food supply chain because of the cultural, social, and economic decisions made by producers and final consumers (Dou et al., 2016; Dorward, 2012). According to the report by Gustavsson et al. (2011), roots and tuber crops, such as the potato, comprise the dominant crop in high income countries. They also showed that the high-income regions' food loss can be attributed to strict grading and quality standards by retailers. Food waste at the consumer level is also high in DCs in comparison to LDCs. Hence, after the World Food Conference in 1974, there has been increasing interest in curbing FLW through different approaches, methods, skills, and innovative technologies (Affognon et al., 2015). Nonetheless, even with consistent efforts, there are not many success stories about attempts to reduce FLW along the entire supply chain (World Bank, 2011). Hence, there is an emerging challenge for researchers and practitioners to develop and implement new concepts for planning and controlling FLW across the supply chain.

Reducing FLW involves recognising the main causes and selecting potential solutions based on specific commodities in a given context. Solutions include evaluating the necessary costs and benefits of assorted options for different actors along the chains. However, success in food waste

reduction requires the continuous involvement of all actors, inside the food chain or at broader levels. This often calls for coordinated action from multiple stakeholders. It also calls for action at a policy level to improve existing policies, such as taxes on food waste or a landfill tax, which can have a positive impact on reducing FLW, or developing specific policies targeted at reducing FLW.

This paper aims to systematically analyse and synthesise the research published in the past 20 years on FLW in the supply chain to identify the root causes of FLW and to analyse the solutions to reduce FLW in both DCs and LDCs. It identifies gaps in FLW assessment and mitigation and considers their implications for future FLW research in both DCs and LDCs. The overall aim of this research is achieved through answering three specific research questions (RQ):

- RQ1- What are the root causes of FLW in the agri-food supply chain in DCs and LDCs?
- RQ2- What innovative measures and effective policies have been implemented to mitigate FLW in DCs and LDCs?
- RQ3- How can an interdisciplinary conceptual framework support the development of sustainable food supply chains to mitigate food loss and waste?

The motivation for this research is to contribute to the normative literature through the development of an integrated system-wide interdisciplinary research approach to answer these RQs. The primary step in developing an interdisciplinary system-wide approach to agri-food research is to describe what the "system" is, what processes are included within the 'system', and where the boundaries are set (Horton et al., 2017; De Steur et al., 2016). The agri-food system comprises the processes and interactions of stakeholders involved in production at the farm-level, including the conversion of plants and animal feed into human food, through the purchasing, preparation, storage, distribution, retailing, and consumption of foodstuffs by and for humans.

Not many studies have attempted to describe the agri-food system boundaries and highlighted the need for an interdisciplinary system-wide approach. Conway (1987) coined the term 'agro-ecosystem' to describe the complete system of agricultural production and then went on to describe the agri-food system with all the processes and participants involved in crop production, including material flows, interactions, inputs, and outputs. Horton et al. (2017) further expanded the range of processes and stakeholders to create an agri-food ecosystem that integrated land-use, harvesting, technology, food processing, storage, distribution, and consumption. Their study demonstrated that losses and waste could occur at all points in the system. The causes are varied and include harsher

climatic conditions or nutrient-poor soils leading to farm yield loss, inadequate storage and inefficient transportation networks leading to post-harvest losses in low and middle-income countries, and wastage at the consumer level leading to food waste in high income countries. However, none of the models has provided an in-depth root cause analysis of FLW that could be helpful in designing strategies and policies for reducing, reusing, and recycling FLW.

The model used by Horton et al. (2017) created an analytical framework for improving resource efficiency and sustainability in food supply chains by simply mentioning how various outputs from the system could be viewed as resources that could be utilised and fed back into the system as inputs. In this model, they described the inputs as fertiliser, seeds, agrochemicals, electricity, fuel, water, machinery, labour, chemicals, infrastructure, and packaging. The outputs were described as animal waste, food waste, biomass, biofuel, and human sewage. The outputs of this model were simply connected (with a dotted line) to the inputs to demonstrate the scope of resource efficiency and sustainability. However, none of these models (including Conway's agro-ecosystem) could demonstrate this process in detail. Given the above-mentioned research gaps, the authors consider FLW occurring in the system (i) at farm level; (ii) during production; (iii) during distribution; (iv) during storage due to pests, spillage, spoilage, and contaminations; and (vi) at the wholesale or retail level. The authors seek to answer the three research questions as diagrammatically illustrated in Figure 1.

Several innovative measures have been identified to see the model's usefulness in preventing or reducing FLW. Within this diagrammatic presentation, the authors have attempted to think beyond the waste prevention phase and have moved towards sustainability practices by adopting waste utilisation measures that will benefit both the environment and the economy. This can be achieved through valorising and re-using the resources and by minimising the emissions of greenhouse gases.

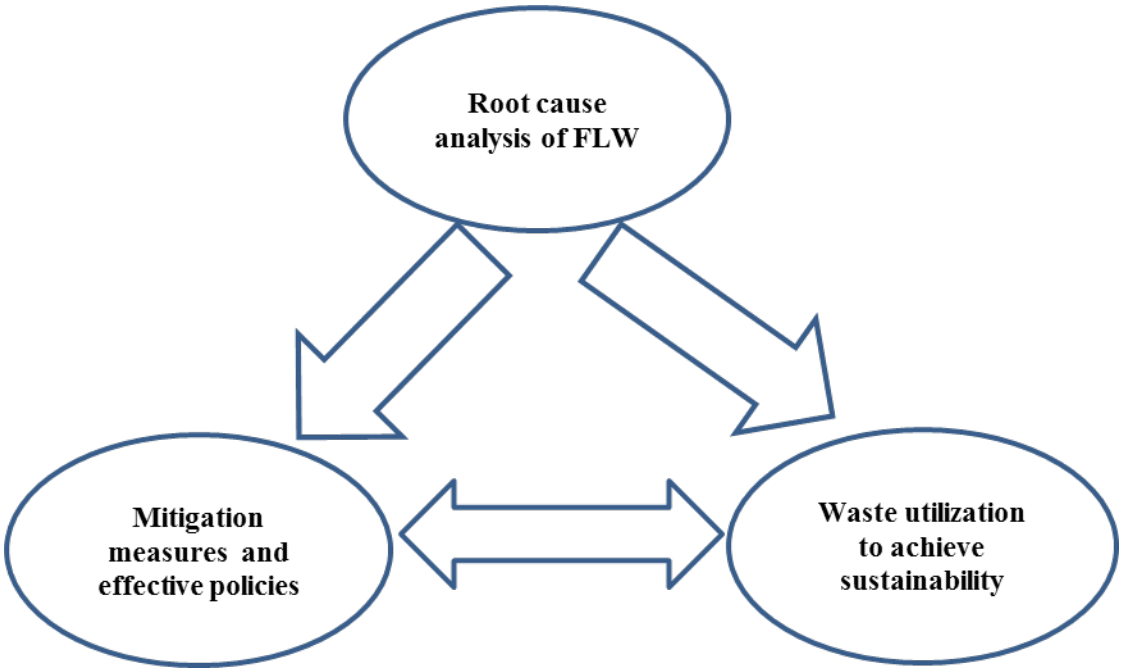

Figure 1. Scope of this research- RQ1, RQ2 & RQ3

The uniqueness of this paper lies in exploring and compiling different interlinked aspects associated with FLW in the food supply chain, i.e., the level of implementation of preventive measures to curb FLW across different economic levels and developments in waste utilisation practices as a sustainable tool, which shows usage at a systems level. The research questions set out in this review stem from the principle of providing new insights and a collective perspective that has not yet been established through the integration of research streams that grew in isolation from each other.

The outcome of this research is an interdisciplinary conceptual framework that considers a system-wide approach to show opportunities for transitioning from a traditional linear supply chain to a circular supply chain. Through this framework, the authors show how losses and wastes from a given system could be utilised as resources across the different stages of a supply chain to extract their maximum value. The presented research also highlights the possible policy interventions needed for the successful implementation of this framework.

2. Research Methodology

Meredith (1993) defined a literature review as a summary of the existing literature through finding the focus, trends, and issues of current research. According to Fink (1998) a literature review is a systematic and reproducible design for identifying, evaluating, and interpreting the existing literature. This definition emphasises the review process as well as the desired results. The critical analysis of the research papers selected for review reveal several un-noticed trends in the literature. The challenges lie in analysing the whole body of literature, which keeps increasing with the development of the domain. Therefore, the researchers put some delimiting criteria to make it possible to provide comprehensive reviews within a defined boundary so as to produce meaningful insights.

The systematic review carried out in this paper follows the three-phase approach outlined by Tranfield et al. (2003) and diagrammatically presented in Figure 2:

- Phase I – Planning the Review
    - Defining an overall research aim and preparing the search protocol
- Phase II – Conducting the Review
    - Identifying, selecting, evaluating, and synthesising the relevant research studies
    - Identifying gaps and defining research questions
- Phase III – Reporting and Dissemination of the Overall Research Findings
    - Descriptive reporting of findings and discussion.

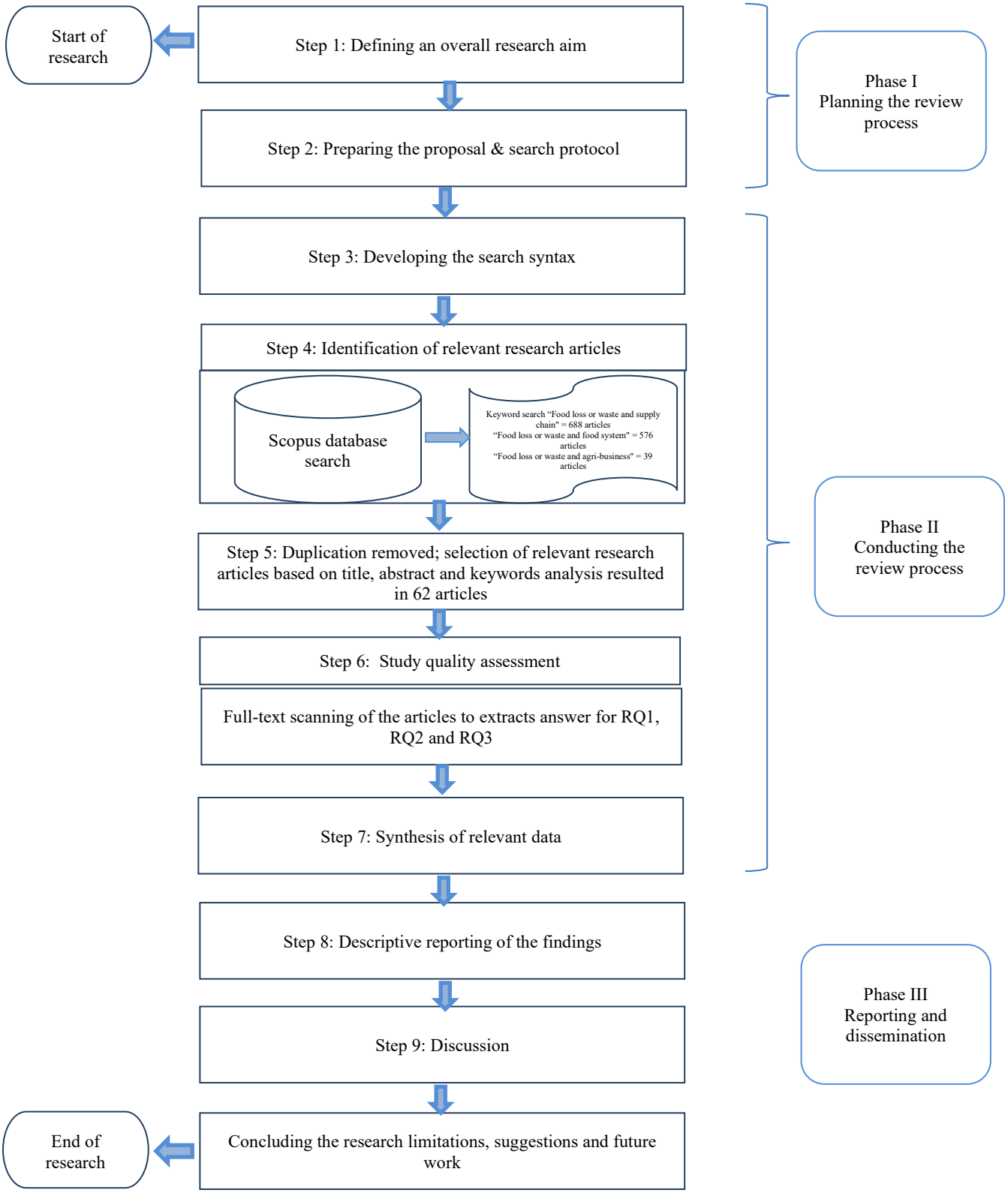

Figure 2. Research design – systematic literature review process (phases as proposed by Tranfield et al. *2003)*

2.1. Delimitations and the search for literature

In a systematic literature review, it is important to specify clear boundaries to establish the scope of the research. In this context, two important considerations are made as follows.

1. This analysis focused only on papers in peer-reviewed scientific journals in English from all fields including management, social sciences, economics, environmental studies, biological sciences etc. We excluded papers written in other languages and that had a technological and behavioural focus.
2. Papers focusing on infrastructure/ technical development for detecting the perishability of fresh products, biological infestation, and the impact analysis of FLW were not included.

The authors involved in producing this paper are three senior university academics and two research assistants with experience in food supply chains and a track record of publishing in peer-reviewed journals. One member of the study team screened articles by title and abstract to eliminate those that clearly did not meet the inclusion criteria. Two members of the study team then separately reviewed the full text of all the remaining articles to determine whether they met the inclusion criteria. A third member resolved any disagreements about whether to include a particular article in the review. Next, two members of the study team separately worked to extract data from each article that met the inclusion criteria, and another member of the team resolved any discrepancies that arose during the data extraction process. Data were entered into a detailed coding form; the data included citation information, study objective, location of study, date of data collection, study methods, food loss and waste mitigation strategy, key results, study limitations noted by author, study limitations noted by reviewer, and key conclusions.

The present research was developed around three questions as outlined in the introduction (i.e., RQ1, RQ2, and RQ3) by adopting the three-phased approach. As this literature review focuses on identifying the factors responsible for FLW, mitigation strategies for FLW, and approaches employed for waste minimisation, it was necessary to adopt a broad-based multi-disciplinary approach to the literature search. The rationale was to build a comprehensive database to ensure broad coverage of the available data from the wide pool of FLW research. Studies were identified by searching Scopus from 1998 to 2018. The search syntax used included search terms referring to "food loss or food waste" combined with "supply chain" or "food system" or "agri-business". The inclusion criteria used for the selection of relevant studies was initially based on screening of the title, abstract, and keywords. To focus on enhancing the quality control, only published peer-

reviewed journal articles written in the English language were selected. A full paper review was performed where relevance of the study was analysed in detail. Care was taken to ensure that the selected articles not only contained FLW-related complications but also highlighted mitigation strategies or waste management practices based in relation to FLW. The database search initially identified 1,303 studies that were of potential relevance. However, after the removal of duplicates, analysis of the title, and screening of the abstract and full article, a total of 62 studies were selected. Although the authors limited the search to peer-reviewed journal articles published in English and deliberately omitted grey literature, such as research reports, books etc., 'grey' literature sources are by no means without value and, indeed, provide valuable policy recommendations in the discussion.

3. Results and findings

The search identified a considerable number of publications over the 20-year period (1998–2018), which were screened for potential relevance according to the pre-set criteria and based on RQ1, RQ2, and RQ3, giving a total of 62 documents. While the grey literature on FLW offered information in the form of books, conference proceedings, working papers, or project reports, these were not considered. However, information from those publications was extracted to support research gaps and reinforce our findings. The profile of the 62 documents gave rise to several observations.

3.1. Descriptive analysis

Figure 3 shows the largest number of publications was recorded in the year 2016 (C= 17; 27%) followed by 2015 (C= 10; 16%). A very low number of publications was recorded during 2008-2013 (2% - 5%). The noticeable increase in the number of publications from 2014 onwards clearly shows a trend of the increasing awareness and significance of this research area among the researchers and practitioners. However, in 2017, the number of publications decreased (C=7; 11%) compared to the previous year. We observed that currently, the majority of papers focus mostly either on impact analysis or infrastructure/ technological developments.

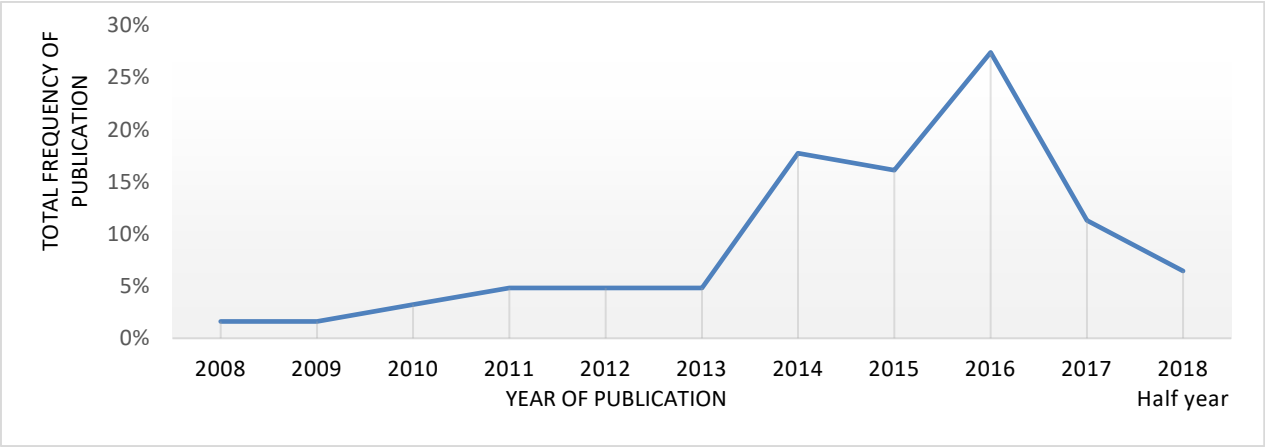

Figure 3. Total number of papers published between 2008 and 2018

Of the total 62 articles, a list of 28 journals was compiled to show which journals were targeted by researchers and academics to publish their work. According to the findings illustrated in Table 1, "Waste Management" is the journal most targeted by researchers (C= 11; 18%), followed by "Journal of Cleaner Production" (C=10; 16%) and "Resources, Conservation and Recycling" (C=8; 13%). The scope of these leading journals is in the area of FSC; thus, they broadly cover most of the issues related to FLW. The journals with their publication frequencies and percentages are presented below in Table 1.

Table 1. Name of journals and total frequency between 2008 and 2019

Name of Journals Extracted from Scopus	**Total**	**Percentage (%)**
Appetite	1	2%
Bioresource Technology	2	3%
British Food Journal	2	3%
Crop Protection	1	2%
Food Policy	5	8%
Food Research International	1	2%
Food Security	1	2%
Fuel	1	2%
Global Food Security	2	3%
Food Control	1	2%
International Journal of Culture, Tourism and Hospitality	1	2%
International Journal of Physical Distribution & Logistics	1	2%
International Journal of Vegetable Science	1	2%
Journal of Cleaner Production	10	16%

Journal of Enterprise Information Management	1	2%
Journal of International Food & Agribusiness Marketing	1	2%
Journal of Retailing and Consumer Services	1	2%
Philosophical Transactions of the Royal Society A	1	2%
Process Safety and Environmental Protection	1	2%
Regional Environmental Change	1	2%
Resources, Conservation and Recycling	8	13%
Science of Total Environment	1	2%
Trends in Biotechnology	1	2%
Waste Management	11	18%
Waste Management & Research	2	3%
World Development	1	2%
Journal of Stored Product Research	1	2%
International Journal of Operations &Production	1	2%
Total	**62**	**100%**

A considerable number of studies (C=34; 55%) were conducted in DCs compared to in LDCs (C= 18; 29%), which indicates a growing concern for FLW in the supply chain among high-income countries, or it could be simply showing an improvement in the levels of food security (Figure 4). It was found that most of the studies covered Europe and Central Asian countries whereas South Asian and sub-Saharan African countries have been largely ignored, which may be due to a lack of focus on this research area.

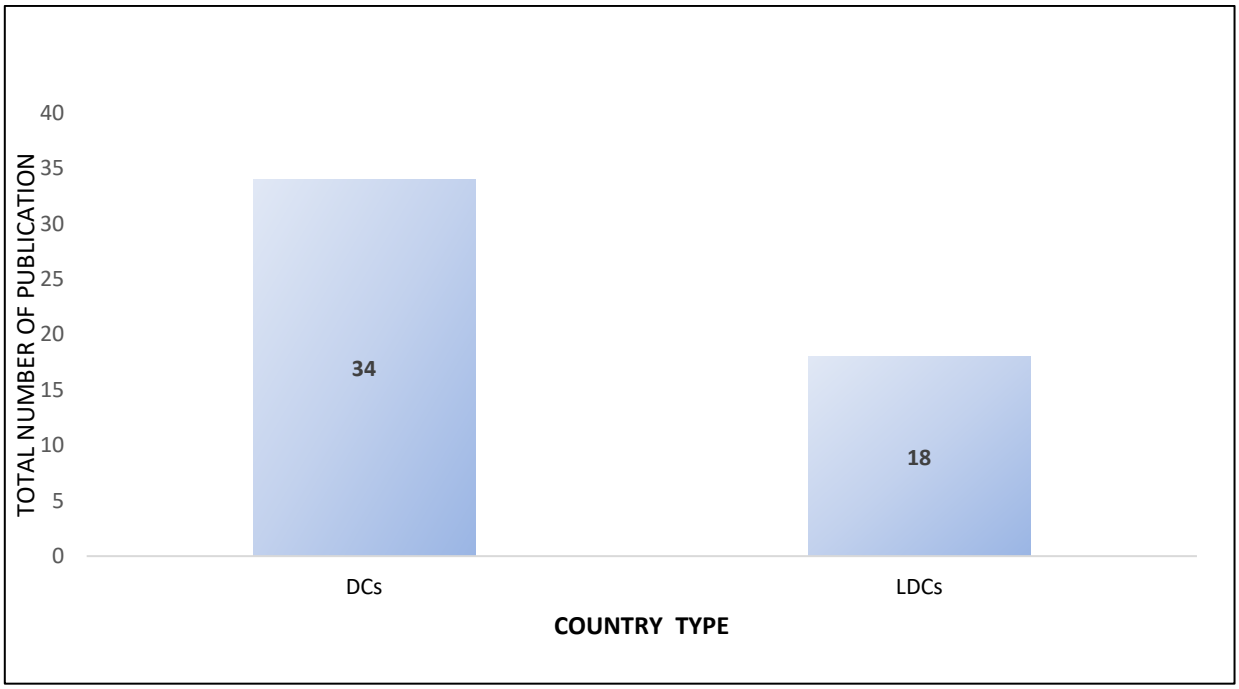

Figure 4. Total number of papers published under different economies

Figure 5 shows most of the work in DCs targets the stage of retail/wholesale (C= 12; 29%) followed by consumption (C=7; 17%) of FSC whereas in LDCs, the focus is on the farm stage (C= 5; 33%). However, while the storage, distribution, and packaging phases of the value chain are largely covered by studies in LDCs, research into the food service industry is totally overlooked in these countries because there is no regulation or no enforcement of the regulation.

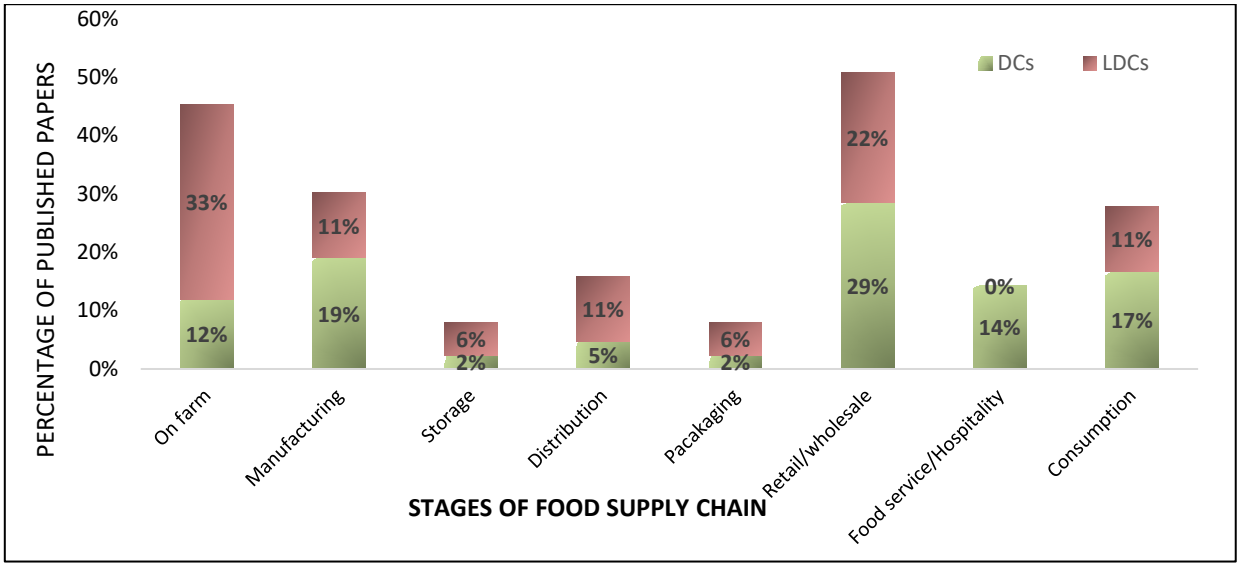

Figure 5. Total number of papers published (in %) under different stages of food supply chain

The research methods employed by the FSC researchers in the selected 62 papers revealed that 8 different research methods are recorded from the present data analysis (Figure 6). However, most studies employed the literature review method (C= 31; 42%) followed by the interview (C=13; 18%) and case study (C=12; 16%) methods.

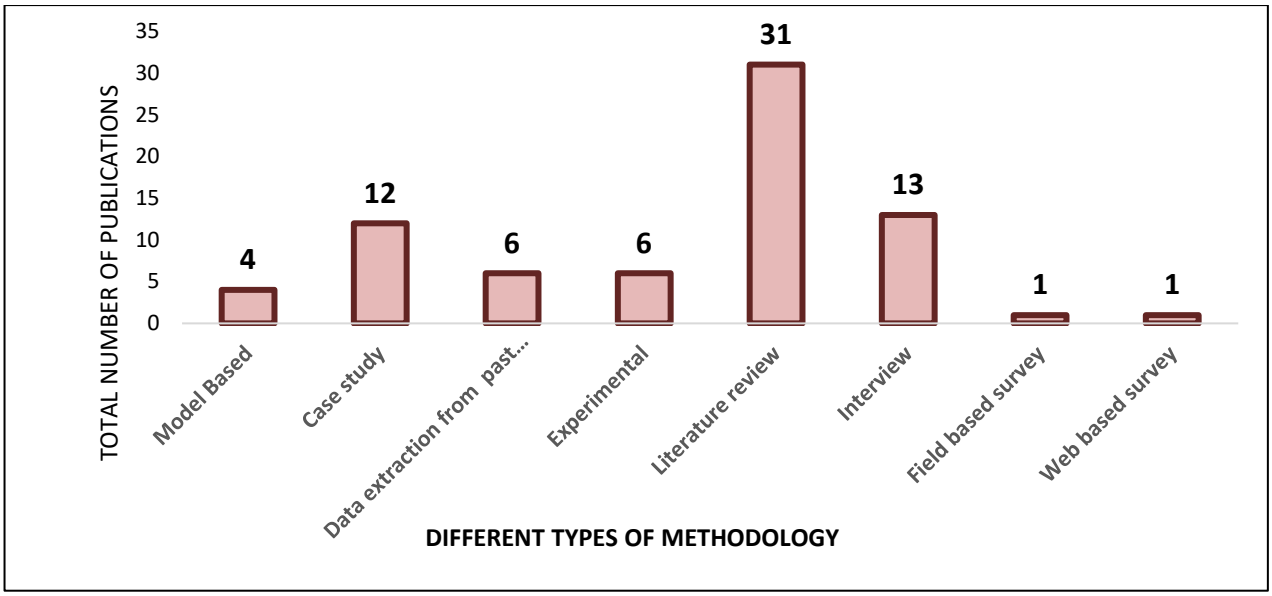

Figure 6. Classification of publication types between 2008 and 2018

As mentioned previously, RQ1, RQ2 and RQ3 were identified based on the three themes emerging from the literature. For clarity, Figure 7 presents a Venn diagram that highlights the number of papers focusing on the three themes and shows that just one paper briefly captures the three themes together. Hence, there is a clear gap in the literature, which this paper aims to fill, and this helps in building a holistic understanding of FLW in both developed and developing countries. Many of the papers focus on analysing the reasons for FLW followed by mitigation strategies. In total, 24 articles discuss both the issues together. There are comparatively very few papers under waste management practices, which shows this issue has been largely ignored by researchers.

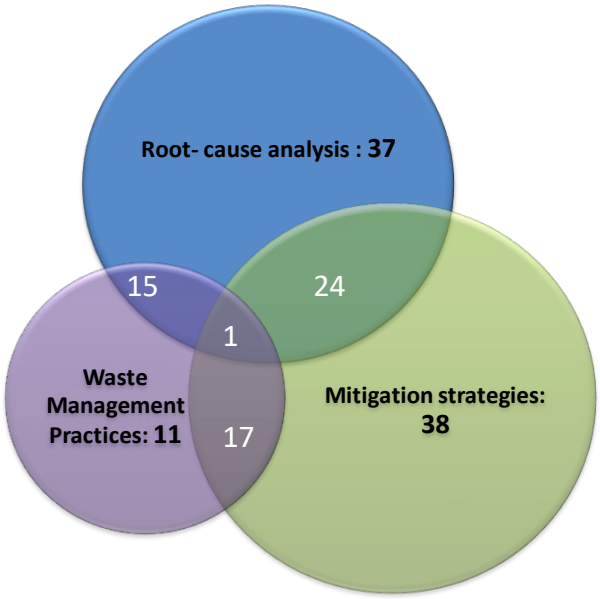

Figure 7. Venn diagram shows publication synergy addressing RQ1, RQ2 & RQ3

As this research is concerned with evaluating the impact of effective policy actions on reducing food wastage, the authors examined 62 articles to see different food-waste-related policy approaches as well as business options that help tackle the issue of food waste in the supply chain. The impact of policies on food wastage is both sensitive and complicated (Chalak et al., 2016; Pearce et al., 2018). For a policy to be effective, it needs to be comprehensive and flexible to involve all stakeholders in the food chain (FAO, 2013). However, in the present study, the authors observed limited information at a country level, with only five articles providing an insight into policy making. Due to the lack of information, the authors looked beyond the 62 articles and took advantage of several government and non-government reports to support the research findings.

An analysis of the distribution of articles against the published year was undertaken to study the trend of research streams from 2008 to 2018. The results are presented in Figure 8. This shows that since 2009, researchers have focused on different aspects of FLW including analysis of the factors responsible for FLW, the protocols for minimising its effects, and the selection of waste management practices to become resource efficient and to reduce greenhouse gas emissions. Progress is sustained and demonstrated in the number of publications under all three categories, which supports the focus of this paper. Substantial research has been conducted on the root-cause analysis of FLW and on mitigation strategies from 2009 (2.70%) to 2016 (32.43%). However, work

on waste management practices started appearing from 2012 (10%) and reached 30% by the end of 2017, which highlights the emerging and growing nature of this field of research.

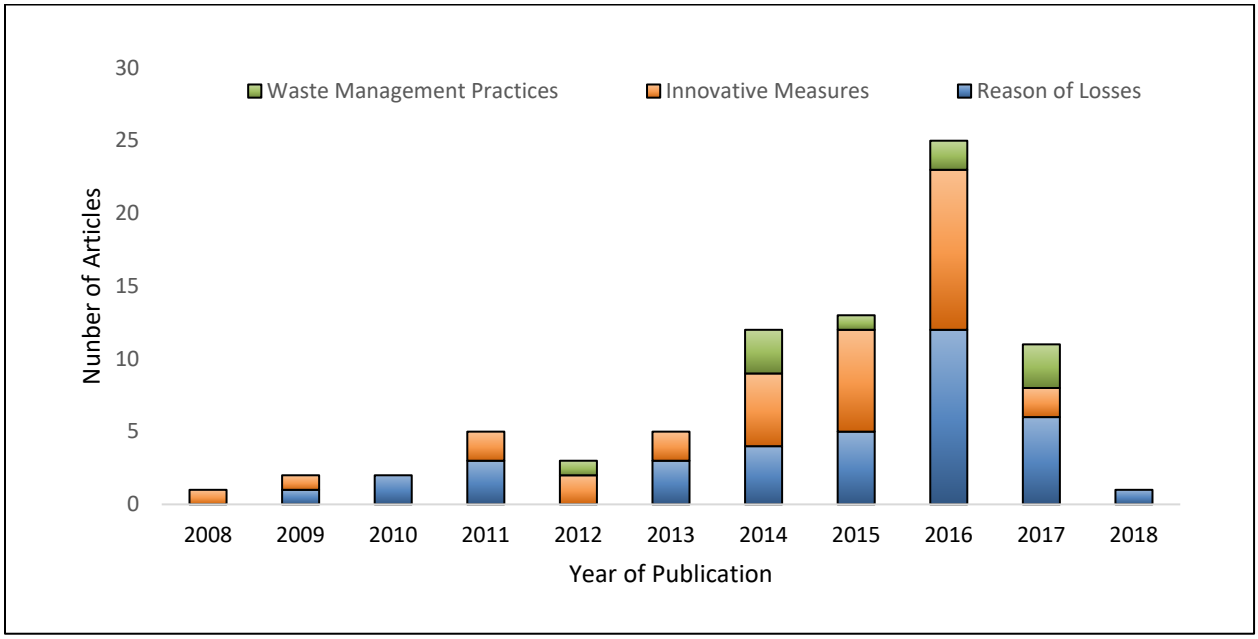

Figure 8. Total number of papers published between 2008 and 2018 under RQ1, RQ2 and RQ3

The geographical locations where the research was conducted are demonstrated in Figure 9. This information was produced based on the location information about the selected publications under review. The analysis revealed that among DCs, the UK is the only country where all three research streams were studied whereas in LDCs, Brazil is the only one where all three aspects of FLW were emphasised.

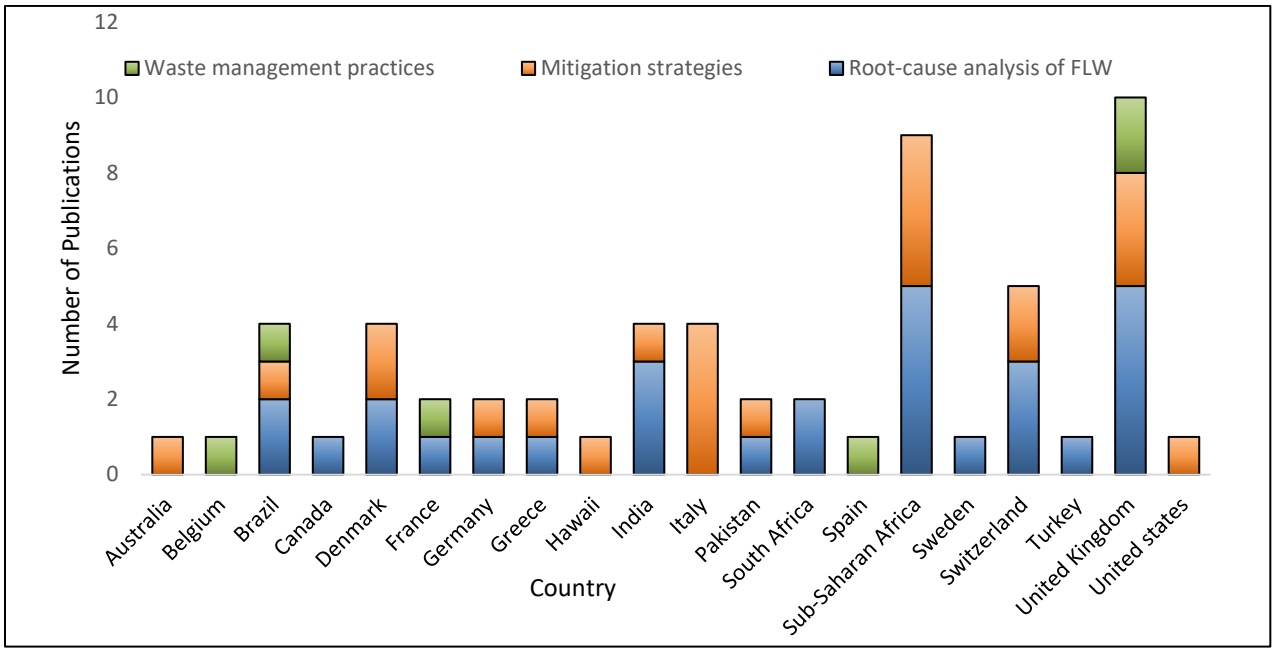

Figure 9. Total number of papers published between 2008 and 2018 in different regions

3.2. Root -cause analysis of FLW

Prior to conducting a detailed analysis of the consequences of food losses in DCs and LDs during production, manufacturing, distribution, retail or wholesale, and consumption, an Ishikawa diagram was developed. This visual tool helps identify the potential causes of food losses (Figure 10a & 10b). A detailed analysis of the causes of the post-harvest loss is performed for each of the above categories. The primary determinants of FLW are the following:

On farm: Poor demand forecasting, which leads to the overproduction of crops (Beretta et al., 2013) that then remain unharvested in the field, is identified as the potential cause of food losses in DCs. A substantial portion of food waste generated at the primary production level originates from sizing demands (Halloran et al., 2014). At the supermarket level, most fruit and vegetables are sold by piece and not by weight, unless packaged. This means the under- and over-sized produce cannot be sold to supermarkets and are often discarded automatically at the production level (Halloran et al., 2014). However, in LDCs, the lack of infrastructure and advanced technical skills to grow and harvest crops have been identified as key contributing factors towards FLW (Sibomana et al., 2016; Affognon et al., 2015). The usage of inferior quality equipment for harvesting in LDCs leads to the breakage of grains (Balaji & Arshinder, 2016).

These are then rejected, as they fail to meet the quality standards set by other stakeholders, such as the purchaser (Sibomana et al., 2016).

Manufacturing: In both DCs and LDCs, there are common complications at this stage of the FSC. Cosmetic standards imposed by the retailers lead to a huge amount of waste despite there being no problem in quality or taste (Matharu et al., 2016; Richter & Bokelmann, 2016). Processed foods may also be lost or wasted because of inefficient factory processes (Matharu et al., 2016; Mena et al., 2011). The usage of poor packaging materials has also been identified as a major cause of quality loss (Mena et al., 2011).

Distribution and retail or wholesale: In DCs, the maximum loss has been observed at this stage of the FSC. Exceeding the expiry date, logistical constraints in terms of a lack of cold storage, and overstocking due to inaccurate ordering and forecasting demand are the main drivers of food loss (Priefer et al., 2016; Gustavsson et al., 2011). In addition, failure to conform to minimum food safety standards (e.g., microbial contamination, pesticide residues), marketing strategies like 'buy one get one free', and packaging defects are also identified as the causes of food loss (Priefer et al., 2016; Gustavsson et al., 2011; Parfitt et al., 2010). However, in LDCs, the lack of temperature-controlled trucks and long-distance transportation causes pathogen-driven losses (Balaji & Arshinder, 2016).

Hospitality/ food service industry: Food loss or waste at this stage is highlighted only by DCs. The food service industry, including restaurants and hospitals, accounts for a considerable amount of food waste due to the portion sizes they offer (Marthinsen et al., 2012; Silvennoinen et al., 2012). Poor menu description, a lack of infrastructure, and staff inability to address consumers' choices are also observed as causes of food waste (Sonnino & McWilliam, 2011).

Storage: Out of the 62 articles, Post-harvest loss during storage is largely emphasised by LDCs. Poor storage conditions can result in losses caused by the combined actions of moulds, insects, rodents, and other pests (Abass et al., 2014). The lack of available cooling technology is a key aspect in the supply chain factors influencing food losses, e.g., milk (Porter & Reay, 2016).

Consumer: At the consumer level, losses occur because of consumers' tastes and preferences, and their purchase planning, that is, decisions on when and how to use foods (Borrello et al., 2017). In addition, there are societal and economic trends that promote food wastage at household levels, such as increasing purchasing powers, decreasing food prices, urbanisation, and the rising number of single households (Jörissen et al., 2015). The evidence revealed that, in LDCs,

the insufficiency and insecurity of food is far greater than in DCs in terms of both affordability and accessibility. The extent of the damages is further increased in LDCs due to the lack of proper governmental policies and immature supply chains.

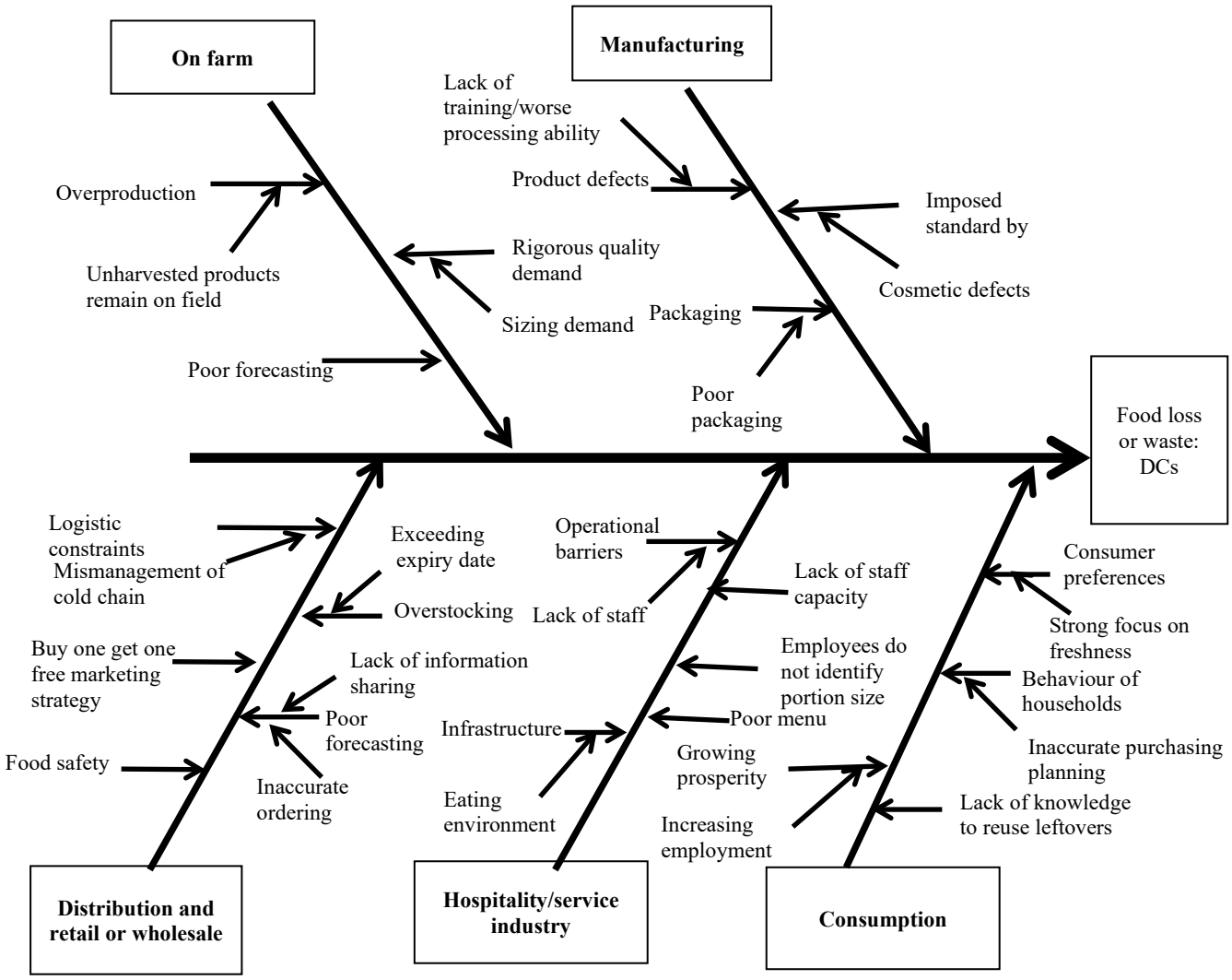

Figure 10a. Root cause analysis of food loss and waste in developed countries

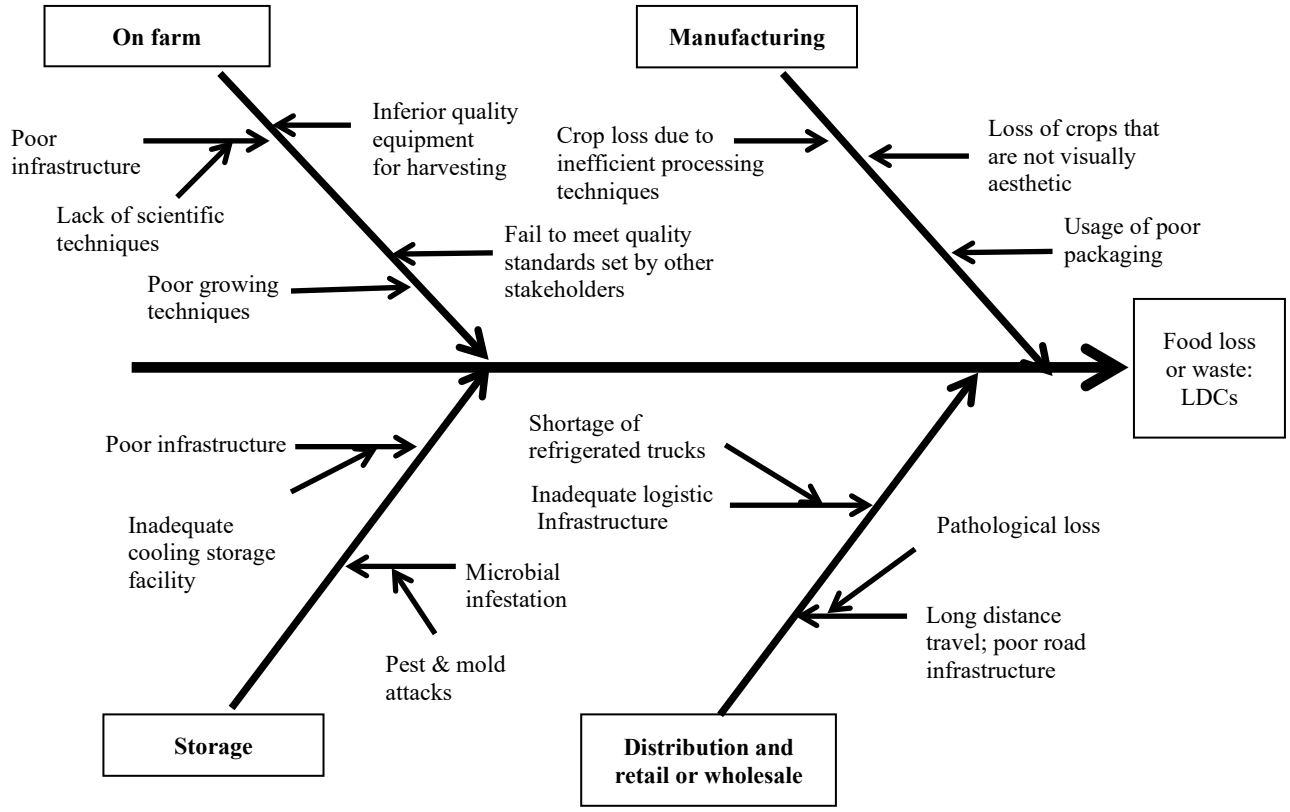

Figure 10b. Root cause analysis of food loss and waste in lesser developing countries

3.3. Mitigation strategies and policies adopted by DCs and LDCs

Food wastage has significant environmental impacts that also create and affect societal costs. Therefore, mitigation of this wastage is crucial for each actor along the food chain. This paper presents a portfolio of potential food wastage mitigation measures that have been adopted to date in both DCs and LDCs.

3.3.1. In developed countries: The present study found 18 out of 30 articles under the DCs category highlighted the range of innovative mitigation strategies across the supply chain (Table 2). According to the observation, reducing food waste requires an integrated food supply chain management approach (Priefer et al., 2016). This is because complexity cannot be resolved at the individual levels, thus highlighting the need for strong cooperation among the different stakeholders (Lipinski et al., 2013). Thus, the information flow across the chain should be encouraged and supported with appropriate tools and the use of agreed principles and protocols. The efficient operation of a supply chain is largely based on forecasts. Interestingly, Kaipia et al.'s (2013) study on the fresh food supply chains of Nordic countries found that the movement of Order Penetration

Point from production to the retail customer allows delayed ordering from the retailers. Therefore, more accurate demand responsiveness can take place. Consumers are also concerned with the aesthetic characteristics, freshness, variety, and price, which also cause the rejection of many good products (Teitscheid et al., 2012; Borrello et al., 2017). The donation of surplus food stock to poor people or communities is also identified as a potential measure to fight against hunger and food insecurity in many DCs. Such interventions or reactions are considered socially and ecologically beneficial (Giuseppe et al., 2014; Beretta et al., 2013). Other studies also provided useful information for reducing food waste at household levels, through participating in cooking courses or implementing household economics education campaigns (Stancu et al., 2016). Based on their findings, efforts to change reuse routines may have a significant impact on food waste reduction, while shopping habits also play a role in reducing purchase volumes.

During the last ten years, food waste in DCs has become an important research theme, and the efforts projected by policy makers aim to address the food waste challenge in a more targeted and sustainable manner (Ponis et al., 2017). Thus, in 2011, the European Commission released a document titled "Roadmap to a Resource Efficient Europe" in which a commitment was made to reduce food waste by 50% by 2020 (Meulen & Boin, 2015). Later, in 2015, the European Commission amended a number of Directives on waste along with an ambitious proposal to promote a 'circular economy' (Meulen & Boin, 2015). In countries like France and the US, food waste has been viewed and dealt with as a public problem (Cloteau and Mourad, 2016). Over the last three years, the French authorities have taken many communication initiatives to educate consumers about food waste and encourage the food industry to be more active in reducing food waste. These initiatives include so-called "anti-gaspi campaign" ("gaspi" comes from "gaspillage" meaning wastage), which published a large amount of information about the importance of reducing food waste in France and explaining how people can help to minimise it. Examples include better understanding of the "use by" and "best before" dates and the promotion of 'ugly' fruit and vegetables (Meulen & Boin, 2015). Similarly, the US Department of Agriculture (USDA) and the Environmental Protection Agency (EPA) have worked in partnership with charities and the private sector and are now targeting a 50% cut in edible food waste by 2030. To help the public better understand how to have the most effective food recovery impact, EPA promulgated a hierarchy prioritising five food recovery actions ranked according to their potential to benefit the environment, society, and the economy (EPA, 2017). The five action levels are as follows:

(i) source reduction

(ii) feeding hungry people

(iii) feeding animals

(iv) industrial uses

(v) composting

Previously, the US enacted laws under the Bill Emerson Good Samaritan Food Donation Act in 1996 and the Food Donation Act in 2008 both of which protect food donors from civil and criminal liability and encourage companies and organisations to donate healthy food that would otherwise go to waste (FAO, 2013). Among the developed nations in Asia, Japan amended the law in 2001 for the Promotion of Recycling and Related Activities for the Treatment of Cyclical Food Resources, which targets the reduction of food waste generation and the promotion and support of food waste recycling into animal feed and fertilizers (UNEP, 2014).

Table 2. Mitigation strategies to curb food loss or waste in developed countries

Authors	**Mitigation strategies**
Richter & Bokelmann (2016) Betz et al. (2015) Ponis et al. (2017) Cicatiello et al. (2016) Stancu et al. (2016) Dou et al. (2016) Beretta et al. (2013) Halloran et al. (2014) Sonnino & McWilliam (2011) Thyberg & Tonjes (2016) Cole et al. (2014)	Public awareness/ communication/ educational campaigns
Garrone et al. (2014a) Garrone et al. (2014b) Giuseppe et al. (2014) Beretta et al. (2013) Chalak et al. (2016) Cicatiello et al. (2016) Thyberg & Tonjes (2016) Garrone et al. (2016)	Food donation
Secondi et al. (2015)	Training
Giuseppe et al. (2014)	Livestock feed
Dixon- Hardy & Curran (2009)	Reusable packaging
Priefer et al. (2016)	Subsidies
Dou et al. (2016)	Innovative technology

Loke & Leung (2015) Secondi et al. (2015) Priefer et al. (2016)	Efficient supply chain management
Garrone et al. (2016)	Surplus food management: remarking; redistribution; marketing and sponsorship; conferment for animal feed
Thyberg & Tonjes (2016)	Logistic improvement; improved and easily understandable labelling system;
Miliute-Plepiene & Plepys (2015)	Near-property collection system,
Cole et al. (2014)	Implementation of zero waste strategy.

3.3.2. In less developed countries: Out of 16 studies under the LDCs category, only six articles discussed ways to minimise FLW (Table 3). Jedermann et al. (2014) suggested that the use of intelligent, quality conscious warehouse management strategies, such as first expired-first-out, can help estimate the shelf-life of fruit. They found that the successful implementation of first-expired-first-out/least-shelf-life-first-out strategies in sub-Saharan Africa gives an accurate recording of temperature/relative humidity conditions from field-packing to house-distribution centre, and the time sensitive sharing of the data among different stakeholders along the supply chain can reduce losses within the supply chain (Sibomana et al., 2016). Improving fresh product packaging can also reduce PHL as observed by Kamrath et al. (2016) and Affognon et al. (2015). Kaminski and Christiaensen (2014) demonstrated that economic incentive, especially the seasonal price gap, along with access to the market could substantially decrease the extent of food loss. Their study shows an important correlation between post-primary education and food loss. Strikingly, if the head of the family (principal earner) has passed primary education, the occurrence of food loss is less likely. Meta-analysis research by Affognon et al. (2015) in sub-Saharan Africa suggested that future post-harvest losses could be reduced across the entire value chain, based on clear identification of the loss-hotpots and socio-economic aspects. According to Aggarwal and Srivastava (2016), food waste reduction could also be achieved by educating managers so that their cautious efforts will lead to cooperative actions with other supply chain partners. The managers at local firms can also develop programs or workshops to educate suppliers about collaborative initiatives to reduce wastage.

In developing countries, it has been recognised that the application of food waste recycling is very limited (Dung et al., 2015) because of poor recovery systems. In addition, there are no guidelines for people about recycling and no proper incentives to adopt food waste recycling (Suchada et al., 2003). To impose and monitor reduction targets, the Malaysian government

implemented a Master Plan on Waste Minimization and National Strategic Plan for Food Waste Management in 2005, which was then complemented by the National Strategic Plan (FAO, 2013). Later, in 2013, the government legislated for the separation of household waste by using separate bins including one bin for organic waste and another for recyclable waste (Alzahrin, 2010). The Plans set targets of 100% separation at source with 20% recycling of organic waste by 2020 and formulating new ideas for composting food waste and promoting investment in alternative food waste treatments (FAO, 2013). In Thailand, the government implemented a National 3Rs Strategy (2011) and the National Climate Change Strategy (2007-2011) to encourage people to separate food waste that supports the 3Rs implementation, the objective being to increase organic waste utilisation by 50% before 2026 (Alice & Janya, 2012). China has also some specific policies and regulations on food waste management, such as the Food Security Law and the 12th Five-Year Plan (2011-2015) for Environmental Protection (Liu, 2013). However, government ministries and agencies in China are currently working independently rather than in a unified way, which causes inefficiency in implementing food waste policies and regulations in China (Dung et al., 2015). Other countries, such as Benin, Cameroon, Kenya, Zambia, Nigeria, India, and the Ukraine have co-operated with NGOs to run projects and campaigns to promote food waste green treatments (composting and Anaerobic Digestion) and to improve the awareness of food waste management among the public (Christian, 2007; Marmolejo et al., 2012). However, these governments have not yet announced any specific regulations to implement food waste management at national levels.

Table 3 Mitigation strategies to curb food loss or waste in less developed countries

Authors	**Mitigation strategies**
Sibomana et al. (2016)	Efficient supply chain management
Affognon et al. (2015) Kamrath et al. (2016)	Improved packaging
Aggarwal & Srivastava (2016)	Training
Kaminski & Christiaensen (2014) Kamrath et al. (2016)	Communication / education
Tostivint et al. (2017)	Improved logistic
Chegere (2018)	Improved handling practices

3.4. Development of waste management practices in DCs and LDCs

The food supply chain waste constitutes a diverse biochemical environment that offers many opportunities for high value-added valorisation. Table 4 illustrates the formation of by-products

from different categories of crop waste in both DCs and LDCs through waste valorisation. Arancon et al. (2013) demonstrated that waste can be valorised by converting waste materials into chemicals, fuels, and reusable materials. While this type of practice has been in existence for a long time and has focused on waste management, due to the rapid depletion of natural and primary resources and increased waste generation and landfill, this technique has now been brought back because of its sustainable and cost-effective characteristics.

A study by Matharu et al. (2016) found that potential by-products from potatoes and oranges in the form of proteins, enzymes, essential oils, and phenolic compounds have several health benefits. Similarly, Vandermeersch et al. (2014) observed that the valorisation of bread waste into animal feed is recognised as the best option from an environmental perspective due to the high dry-matter content of the bread waste. Similarly, research by Redlingshöfer et al. (2017) in Turkey highlighted the need for energy to grow crops, which could be naturally achieved through using biodegradable waste as an energy source by growing energy crops in fallow lands and using the biomass that is lost during the initial steps of the food supply chain. Accordingly, substantial effort is necessary to decrease and manage FLW, which should involve working within and contributing to the development of new agricultural, industrial, and environmental policies. Participation at all levels is necessary to make a difference in this field.

Table 4. Food waste utilisation in developed and lesser developing countries

Authors	Country type	Region	Crop type	Waste management practices
Matharu et al. (2016)	LDCs	Brazil China India	Potato Orange	Recovery of valuable chemicals
Kuczman et al. (2018)	LDCs	Brazil	Beans Rice Pasta Tubers Vegetables Meats Sausages	Anaerobic digestion for energy recovery
Vandermeersch et al. (2014)	DCs	Belgium	Bread	Animal feed

Salihoglu et al. (2018)	DCs	Turkey	Fish Vegetables Cereals Diary Confectionary	Energy production
Beausang et al. (2017)	DCs	Scotland	Fruits and vegetables	Anaerobic digestion Animal feed Composting Fertilizer Redistribution
Redlingshöfer et al. (2017)	DCs	France	Cereal and pulses Oil crops Fruits and vegetables Dairy	Food donation Animal feed

4. Towards a conceptual framework: implementation of circular economy concept in the food supply chain

According to the reviewed literature, FLW is defined in several ways. FLW is grouped into three categories based on the definitions described in WRAP (2009): (1) avoidable losses refer to food and drink thrown away because they are no longer wanted, e.g., because they have perished or have exceeded their date of expiry due to deterioration (e.g., rotting, decomposition); (2) avoidable losses refer to those foods that could be used in another form or by other users (e.g., potato or pumpkin skins), or that are sorted out due to specific quality criteria (e.g., bent carrots); (3) unavoidable losses (e.g., banana skins, coffee grounds, tea leaves, and inedible slaughter waste) refer to food that is not edible under any circumstances.

The authors advocate food waste reduction and prevention at the outset but also see an opportunity of obtaining value from so-called unavoidable losses because of harvesting and processing. A value gap exists between the food supply chain waste sent for animal feed and that used for composting and energy recovery, which may be exploited (valorised) for high value-added chemicals, functional materials, and bioenergy. Studies undertaken so far on various aspects of FLW indicate that data on food waste generation and its fate (e.g. recovered, redistributed) is scarce.

In recent years, the European Commission has been considering serious action on the issue of tackling FLW by introducing its new Circular Economy Package to inspire Europe's transition towards a circular economy, which will increase global competitiveness, encourage sustainable growth, and generate new opportunities. The global drivers for a bio-based economy, enhanced bio-

resource utilisation, and the transition from a linear to a circular-economy for a sustainable 21st century seem very compelling. However, existing business models for the circular economy are less dynamic and non-inclusive and seem unable to support every kind of company in designing a circular business model (Lewandowski, 2016).

A circular economy in agriculture emphasises using minimal inputs and closing nutrient loops. In the present investigation, the authors conceptualise the practical implementation of a circular economy on the potato supply chain to understand the value of potato waste and its utilisation (Figure 11). The potato was selected because of its high economic value and its ranking as the fourth main crop after rice, wheat, and maize. The potato is in use in the human diet across the world. With the development of potato-processing industries, a complete utilisation of the raw material shows a high potential for practically implementing a circular supply chain. Traditionally, potato peel waste is used for producing low value animal feed, fertilizer, or the raw material of biogas, which wastes large amounts of essential nutrients, such as antioxidant, anti-bacterial, apoptotic, chemo-preventive, and anti-inflammatory properties (Wu, 2016). Several reports have suggested the usefulness of potato peel waste in food processing, phyto-pharmaceutical, and biosynthesis industries, which increases the value of potato peel recycling. Therefore, the authors have attempted to illustrate the different types of waste occurrence in the potato supply chain.

4.1. Waste utilisation/ recovery of potato waste

4.1.1. Edible waste: Figure 11 shows that the rejected small or slightly damaged potatoes which are unsuitable for retail marketing or chipping and which are considered as avoidable loss can be diverted to the dehydrating industry. They can then be converted into potato flakes, potato flour, and potato starch (FAO, 2008). Volunteers from different organisations who work for charities can rescue those potatoes and transform them for processing. Furthermore, surplus potatoes can also be used as stock feed for cattle and pigs, which would, in turn, reduce the need to import energy rich feedstuffs (Fallows & Wheelock, 1982).

4.1.2. By-product waste: Potato processing industries that produce potato chips generate a huge volume of potato peel as a by-product, i.e., a possibly avoidable loss can cause environmental pollution due to its microbial spoilage. Traditionally, potato peel waste is used to produce low value animal feed and fertilizer. However, several biomolecules are now extracted from potato peel waste, such as lactic acid and phenolic acids, which have an important usage in the food industry as food preservatives and flavouring agents (Liang & McDonald, 2014; Maldonado et al., 2014). Indeed,

great progress has been made in extracting lactic acid and other biochemicals from potato peel waste. This finding also highlights the need for interdisciplinary research to capture and understand all possible leaks within the food system along with the role of different stakeholders for generating value from the wastes/ losses so that the system can be truly circular.

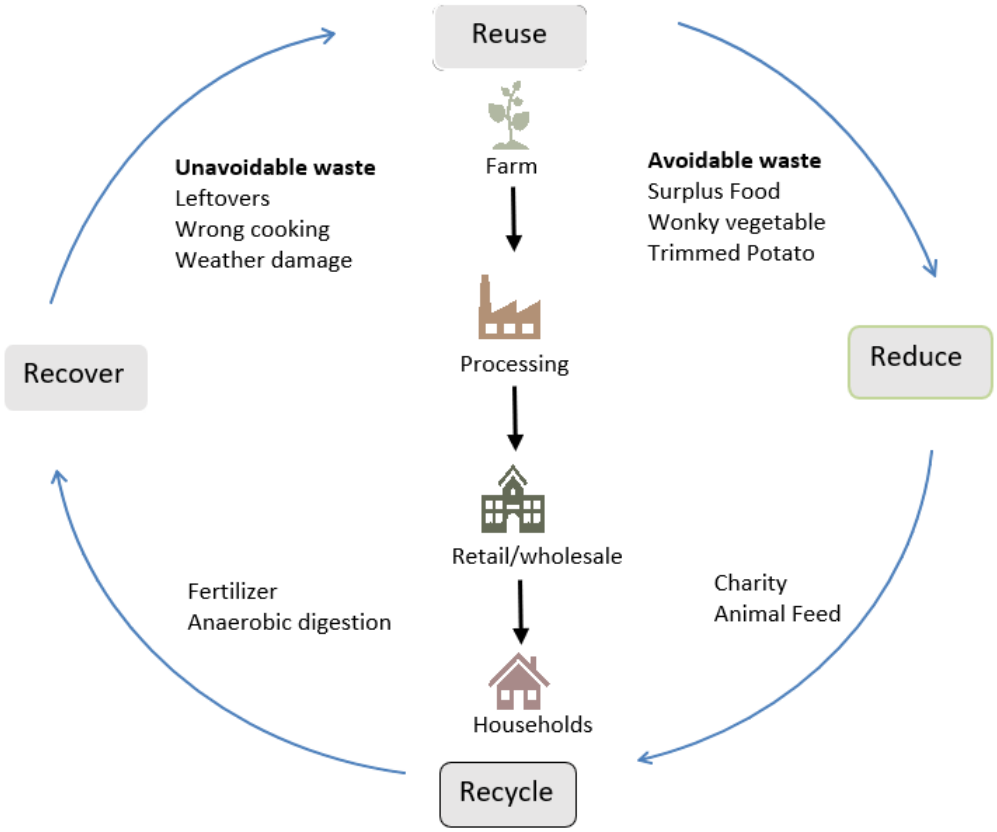

Figure 11. An interdisciplinary conceptual framework: Potato supply chain through the lens of circular economy

5. Discussion

The extensive analysis of secondary data available on FLW shows that numerous studies have been undertaken to assess the losses in quantity and quality in many countries. The authors of this study have provided an insight into the major causes of FLW generation, metaphorically walking through the food chain from farm to fork, and have found that food is lost and wasted throughout the supply chain, from the initial agricultural production to the final household consumption.

5.1. Trends and insights: key causes of FLW in DCs and LDCs

The present study has analysed the causes of FLW in both types of countries, that is, developed and less developed countries. Many causes are common across products, and some of the causes are not the result of management practices or human decisions (such as short shelf-life and weather fluctuations). The analyses also showed that most of the causes have interdependencies, and they are part of a complex web of interdependent causes and effects. These issues motivated the authors to perform further analysis, which could help develop a deeper understanding of the complexity of the problems and identify the root causes. Thus, an Ishikawa diagram was used to identify the root causes of FLW in both DCs and LDCs, and these are described below:

Food losses and wastes in both DCs and LDCs can be attributed to four main factors:

(i) Over production: Over production plays a significant role in wealthy economies (Parfitt et al., 2010) where people can afford to throw food away. At production and manufacturing levels, most of the losses are encountered due to cosmetic defects, such as bent carrots. Even though the products are of perfect nutritional quality, producers will often need to overproduce to meet extra requirements if required at short notice (Parfitt et al., 2010; Wesana et al., 2019).

(ii) Forecasting: Poor forecasting is one of the most common issues identified that cause FLW. However, according to Mena et al. (2014), estimating the demand for a product is a complex task, which can be affected by many factors, such as the weather, seasonality, marketing campaigns, product launches, promotions, and special occasions, such as Eid, Christmas, and Easter. Recently, several forecasting practices have been introduced in the industry, with some companies using a scientific approach while others use more informal methods (WRAP, 2011). Improving forecasting practices and using up-to-date data mining models can reduce forecast errors. However, it must be recognized that uncertainty will continue to exist, and forecast errors cannot be eliminated completely. When information is limited, variations between forecasts and orders increase, and it leads to wastage.

(iii) Technical inefficiency: Poor or low-tech approaches to the farming, storage, and transportation of crops are primary factors contributing to FLW, particularly in LDCs (Bond et al., 2013). This may occur through out-dated farming techniques whereby food is damaged or remains unharvested and left to rot due to poor practice (Bond et al., 2013). This type of harvesting is normally followed by inappropriate storage, where there is insufficient cooling to keep crops fresh, which leads to increased biodegradation mainly due to dense storage techniques that create excess heat (Chegere, 2018). Further losses occur during the transportation of food, primarily due to the lack of

refrigeration or to damage caused to badly secured food products in transport (Balaji & Arshinder, 2016).

(iv) Consumer behaviour: Food waste at the household level is a complex issue relating to consumer personality and individual differences (Swami et al., 2011). It could be influenced by shopping habits and kitchen practices (Stefan et al., 2013). Furthermore, factors such as the types, size, and packaging of food, and where and how it is bought, affect waste volume (Capone et al., 2014). In addition to the everyday causes of food waste, there are also societal and economic trends, which promote the wastage of food, mainly at a household level. As Jörissen et al. (2015) showed, this is due to several factors, such as growing prosperity, decreasing food prices, urbanisation, and the rising number of single households. Furthermore, there are behavioural factors, such as shopping frequency, proximity to a supermarket, and the size of the shop. Williams et al. (2012) demonstrated that there is more food waste when people shop in large supermarkets, while food waste decreases when purchasing takes place in different shopping facilities.

5.2. Trends and insights: Mitigation strategies for reducing FLW in DCs and LDCs

The issue of FLW is high on the political agenda in industrialized countries whereas, in developing countries, this issue is becoming an immense problem due to changes in the food systems owing to rapid urbanization, the expansion of supermarket chains, and changes in diets and lifestyles. Waste mitigation strategies require the consideration of unique approaches and intervention techniques to tackle FLW. The present literature review has indicated that developed nations have opted to minimise FLW across the food supply chain by implementing effective food waste prevention actions at all levels (global, national, regional, and local) and by engaging all the key players in order to build the integrated programmes required to effect change throughout the food value chain. According to Thyberg and Tonjes' (2016) study, food waste prevention falls under three key areas: "values" - providing people with knowledge on food waste so that they want to change their behaviour, "skills" - increasing abilities to be able to reduce food waste (e.g., through training), and "logistics" - including better forecasting practices, improved packaging storage facilities, and donations. Food donations are another measure to reduce food losses, and they are highly beneficial, both socially and ecologically. However, the donation of food is limited to DCs.

A wide variety of awareness campaigns exist throughout Europe, aiming to reinforce the importance of food waste prevention and to increase the respect for food by providing tips on the

purchase, shelf life, storage, preparation, and recovery of food. One of the most famous and successful campaigns in Europe is certainly the British 'Love Food Hate Waste' campaign, supported by the government and operated by WRAP, which was launched in 2007. These efforts helped to reduce household food waste in the UK by 21% between 2007 and 2012 (WRAP, 2012). Countries such as France, the Netherlands, and the UK have included food systems as part of the curricula in schools. Many awareness campaigns through the social media have also been launched by the UK supermarkets to bring about behavioural changes among consumers towards food waste reduction (Young et al., 2017). This research suggests that not only behavioural change is needed to reduce food waste, but also, ultimately, it requires initiatives from the food industry or from the government rather than from individual companies alone. Measures such as the abolishment of subsidies on food are recommended by the Swiss WWF (WWF, 2012). For example, a thorough review of tax regulations, mainly of the Value Added Tax (VAT) Regulation in all EU member states can reduce food waste (Marthinsen et al., 2012). Meanwhile, the governments of France and Italy have gone a step further by mandating the supermarkets to donate unsold produce to charity or to otherwise make use of surplus inventory.

In LDCs, several initiatives have been taken by governments to curb FLW through education, training, and collaboration between farmers and small-scale suppliers. However, upgrading the infrastructure is the only way to mitigate FLW in LDCs. Therefore, a strong step towards the reduction of FLW among small farmers is much needed in LDCs, as they live on the margins of food insecurity (Gustavsson et al., 2011). Sibomana et al. (2016) pointed out the successful implementation of FEFO/LSFO (first-expired-first-out/least-shelf-life-first-out) strategies in sub-Saharan Africa as a potential method that records temperature/relative humidity conditions from field to packinghouse to distribution centre. FEFO/LSFO warehouse management strategies can reduce losses within the supply chain. Kaminski and Christiaensen (2014) showed economic incentives (seasonal price gap) and climatic factors (low temperature) can reduce food loss. That low levels of education and a lack of market access lead to higher FLW in LDCs suggests that policy interventions outside the agricultural sector are needed (World Bank, 2015). Improving access to markets and encouraging farmers (or, rather, their children) to continue to secondary school will reduce FLW in the long run.

Liu et al. (2013) and Thi et al. (2015) suggested that in LDCs, there is an urgent need for more investment in an improved storage, transportation, and cooling infrastructure. There is also a

need to increase producers' access to food processing, packaging, and new markets beyond their local ones (Liu et al., 2013). An FAO and World Bank report suggested new technologies as well as best management practices could significantly reduce FLW in developing nations (FAO-World Bank, 2010).

Increasingly tighter regulations pertaining to organic waste, and the demand for renewable chemicals and fuels, are pushing the manufacturing industry toward higher levels of sustainability to improve cost-effectiveness and meet customer demand. A large number of prevention and mitigation measures have been proposed by various countries and have been already set in place to reduce food waste (FAO, 2014b). However, the development of environmentally sound and innovative strategies to process food waste is an area of increasing importance in our society.

According to a US EPA report, food waste is the single largest type of waste entering into landfill (Nishida, 2014). Wasted food also leads to increased greenhouse gas emissions from landfill, such as methane and carbon dioxide (Hall et al., 2009) as well as representing a significant protein loss. Therefore, the environmental impact of food waste is twofold (Morone, 2016): (1) the depletion of natural resources used for the production and distribution of food, and (2) the costs associated with waste disposal. There is growing interest in whether these two problems (waste disposal and resource depletion) can be solved together through the utilisation of waste as a resource using green and sustainable technologies (Thi et al., 2016; Luque & Clark, 2013).

The current investigation has suggested alternative ways in which food waste can be valorised to produce energy, animal feed, and valuable products, such as chemicals, that encourage a move towards a "zero-waste supply chain". Composting, regenerated animal feed, incineration, anaerobic digestion, and related first-generation strategies have been proposed and investigated for a long time. Some of these techniques have been successfully commercialised. The amount generated as food waste in our everyday life along with the malfunction of storage facilities creates a huge quantity of food waste which essentially requires larger processing facilities. In addition, the variation in the composition of food waste affects the quality of regenerated products such as compost and animal feed. Therefore, it decreases the products' competitiveness in the market. In this context, it is pivotal to overcome the existing technological challenges faced by the conventional food waste valorisation methods and the transition towards the development of eco-friendly and cost-effective recycling methods (Zhang et al., 2013; Leung et al., 2012).

As mentioned earlier in this paper about the complexity of FLW and its causes, which range from inadequacies in storage technologies and facilities to issues in demand forecasting and inventory planning, these problems are exacerbated by the lack of skilled human capital, and the existing networks of researchers focusing on FLW are not fully connected. To tackle this global problem, a paradigm shift in interdisciplinary and collaborative research is required to bring together data scientists, technology specialists, operations and supply chain experts, and economists as well as scientists from agriculture, engineering, and behavioural economics research to provide robust data and solutions to reduce FLW. Future efforts could be encouraged through providing funding schemes to recruit highly qualified scientists and network building to incentivise new frameworks to facilitate interdisciplinary collaborations (Alamar et al., 2018).

6. Policy implications

The target set by SDG 12.3, for halving per capita food waste at the production, retail, and consumer levels along the supply chain, essentially requires a multi-faceted policy approach along with mitigation strategies. Based on previous research, it is necessary to address multiple prevention mechanisms simultaneously because prevention is not created by one factor but by many actions (Cox et al., 2010). Moreover, waste prevention requires changes in people's behaviour, at both the company and individual levels (Thyberg & Tonjes, 2016). It has been observed that national circumstances and cultural diversities have also been linked to food wastage patterns (BioIntelligence Service, 2011), which may differ from region to region and country to country. This indicates that effective approaches to food waste prevention may also differ (Buzby et al., 2011). Figure 9 provides a country wise analysis of 62 articles, which gives an idea about how different geographic regions have taken on board the mission to prevent and reduce FLW. Based on the obtained results, this paper critically examines FLW-related policies in both DCs and LDCs.

The Waste Prevention Programme for England sets out to motivate businesses to contribute to the sustainable economy by creating alternative business models in which waste can be re-designed to make improved products and services. According to WRAP estimates, the retail sector in the UK potentially produces at least 110,000 tonnes of surplus food each year; however, out of that, only 10,000 tonnes of food is directed for redistribution to charities. According to the food waste hierarchy set out by WRAP, the redistribution of surplus food to people followed by converting it to animal feed are the best options for preventing and managing food waste in terms

of minimising the impact on the environment. But concerns have been expressed by FareShare that food is often sent for anaerobic digestion instead of feeding people even though anaerobic digestion comes further down the food waste hierarchy. This indicates a distortion of the food waste hierarchy. Therefore, urgent legislation needs to be implemented to improve redistribution rates in the UK similar to the legislation established in France in 2016, which made clear to all retailers that above a specified amount, food cannot be destroyed or sent to landfill. Food redistribution practices in the UK are currently limited because redistribution efforts are utterly fragmented and function independently of each other (Facchini et al., 2017). At this moment, it is essential to have governmental support through fiscal incentives so that it does not cost businesses more to redistribute surplus food to charities and to develop a larger and more coherent surplus food redistribution system. This would ensure economic incentives that are more aligned with food waste prevention and the recovery of food's multidimensional value. Apart from this, retailers in DCs have strict but unnecessary cosmetic standards for fruit and vegetables. This results in "wonky vegetables" either not being sold or being sold at discounted prices. Supermarkets' standards are a contributing factor to FLW in high income countries. The campaign ran by WRAP across the UK and Europe has helped prevent 137,000 tons of food waste from households since 2007 (e.g., WRAP, 2012). However, to achieve more effective results, information providers should address specific knowledge gaps that drive wasteful practices. For instance, it is important to have knowledge about the shelf-life of fresh food and the usage of leftovers (Farr-Wharton et al., 2014; Jörissen et al., 2015).

In the case of LDCs, the level of food losses is unacceptably high, and accurate data of these losses is still lacking (Affognon et al., 2015). Food losses have been shown to have significant implications for the growth of smallholder farmers in terms of their income and prosperity (Fan, 2017). Due to on-farm losses, the quantity of crops deteriorates, thereby reducing the income of the farmers. Therefore, it is imperative to reduce food losses to improve food security and nutrition, and to increase the income of smallholders.

Based on our investigation, there is a need for more investment for an improved storage, transportation, and cooling infrastructure. There is also an urgent need to increase producers' access to food processing, packaging, and new markets beyond their local ones (Liu et al., 2013). A joint FAO and World Bank report suggests that technologies and practices, such as postharvest grain management, pest management, enhanced storage facilities, and enabling policies could

significantly reduce food loss in Africa (Kaminski & Christiaensen, 2014). In addition, poor quality road networks present major issue for growers, wholesalers, and retailers, especially for people who produce/sell perishable fruits and vegetables, as they suffer losses due to the lack of transportation infrastructure.

There is also a lack of reliable and adequate cold chain facilities in sub-Saharan Africa, which is one of the main causes of the loss of perishable products (Gustavsson et al., 2011). Here the issue is the development of a reliable cold chain infrastructure. Therefore, governments and private sector investors could improve storage and cold chain facilities as well as transportation in these regions (Choudhury, 2006). Furthermore, small-scale farmers could also be supported by the provision of improved financing and credit to allow them to diversify or scale their production according to the demand. The World Food Programme, which is considering food loss as part of some five-year country plans in Africa, has launched the 'Farm to Market Alliance' (World Food Program, 2017). The International Fund for Agricultural Development (IFAD) is also working through loan and grant programmes along with both governments and the private sector to reduce the food losses experienced by smallholder farmers (IFAD, 2019). In addition to this, IFAD has partnered with a range of donors to scale up its impact on food loss reduction, with a strong focus on knowledge generation and policy engagement.

7. Conclusions and future research

The present literature review was aimed at identifying the root causes of FLW in the food supply chain and identifying the gaps in their assessment and mitigation in both DCs and LDCs. This uses a robust methodology for screening relevant studies and for reviewing and analysing the available evidence related to aspects of FLW. The distribution of FLW along the food chain varies greatly by region and product. In high-income countries, most of the FLW occur at the distribution and consumption levels whereas in low-income countries, FLW are concentrated in the production and post-harvest stages. Heterogeneity of definitions, metrics, and measurement protocols and the lack of standards for data collection are some of the difficulties encountered while doing a comparative analysis between different countries and commodities. This is a barrier for identifying the causes and extent of FLW, designing the solutions, prioritising the action, and monitoring the progress in the process of FLW reduction. Therefore, a strong call for the development of global

protocols to measure FLW is imperative, given the large number of variables and country specificities, to achieve the harmonisation of definitions and measurement methods.

It was found that research on these issues is mainly limited in DCs compared to LDCs. The root-cause analysis highlights the driving factors responsible for FLW in both DCs and LDCs. In DCs, large quantities of food loss occur at the retail stage due to high quality standards, which reject food items not perfect in shape or appearance or that exceed the best-before or expiry date, and due to inaccurate forecasting demand. At the consumer level, inefficient purchase planning, the incorrect interpretation of best-before and expiry dates, the cooking of oversized meals, and the lack of leftover usage contributes to the large amounts of waste; these are coupled with the careless attitude of some consumers who can afford to waste food. Poor harvesting techniques, the lack of storage and cooling facilities, and inadequate infrastructure and packaging are the major reasons for food loss in LDCs. The present investigation has shown that DCs have improved the performance of the food supply chain by reducing FLW through raising the awareness of staff, increasing the sensitisation of consumers, and promoting collaboration among stakeholders. The initiatives are currently being undertaken by governments through education, training, and collaboration between farmers and small-scale suppliers in LDCs. Furthermore, some researchers have highlighted that the donation of surplus food to charities is a popular way to tackle the food waste problem in DCs. However, this area of research is underdeveloped, and there is a clear lack of research in food redistribution supply chains in LDCs.

The development of appropriate eco-friendly reprocessing technologies that can convert all the valuable components present in the waste into valuable products and reduce the amount of waste going to landfill is much needed to achieve net reductions. In addition to innovative technologies and food waste reduction, circular economy sustainability solutions are required to support the closing of nutrient loss loops and promote the principles of recovery and re-use to raise the value of waste materials.

Moreover, the prevention of FLW through the lens of the circular economy is a reasonably new concept, and new theories are required to understand this area of research. Future researchers could also address the applicability of a circular economy model through a holistic interdisciplinary and integrated approach for the complete utilisation of FLW in reducing waste as well as recovering valuable by-products, thus moving towards total depollution (zero waste). Before 2015, it was observed that there was no policy applicability for the concept of a circular economy to the whole

agri-food system in the EU. However, recently, the European Commission (2015) has initiated an important drive to support the transition towards a more circular economy in European countries. It is, therefore, essential to keep the momentum going at all the levels, through working together with multi-stakeholders and by understanding the barriers and drivers for facilitating such transition, as well as the role of industries, practitioners, and academicians to help achieve the full potential of the circular economy model. In developing nations, only China is leading in implementing the circular economy model. Therefore, policymakers and decision makers need to work collaboratively to promote the concept of a circular economy among other developing countries. Further, a theoretical research gap is represented by the fact that, to date, circular economy research has mainly been confined to journals from the environmental sciences domain. It appears, then, that the penetration of the concept of a circular economy in disciplines such as economics, management, and engineering is still in its infancy; in particular, it is surprising that no contribution about the topic has been published in any mainstream economics/management journal focusing on the food supply chain. This seems to suggest that a critical evaluation of the circular economy paradigm and of its economic and managerial implications has not yet been conducted, thus representing a major research gap. Additionally, the specific geographical focus of many of these journals also indicates that the penetration of these concepts in the academic community is at an early stage, despite increasing media coverage and legislation.

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