Applying Value Stream Mapping to reduce food losses in supply chains: a systematic review

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Abstract:

The interest to reduce food losses and wastes has grown considerably in order to guarantee adequate food for the fast growing population. We used a systematic review to show the potential of Value Stream Mapping not only to identify and reduce food losses and wastes, but also as a way establish links with nutrient retention in supply chains. The review complied literature from 24 studies that applied VSM in the agri-food industry. The results exhibit the capacity of VSM which identified primary production, processing, storage, food service and/or consumption as susceptible hot spots for losses and wastes. The analysis further revealed discarding and nutrient loss as the main forms of loss/waste in food, which were adapted to four out of seven lean wastes. This paper presents the state of the art of compatibility of lean practices in the agri-food industry by identifying lead time as the most applicable performance indicator. VSM was also found compatible with other lean tools such as Just-In-Time and 5S which are continuous improvement strategies, as well as simulation modelling that enhances adoption. In order to ensure successful application of lean practices aimed at minimizing food losses and wastes, multi-stakeholder collaboration along the entire food supply chain is indispensable.

Introduction

This year marks the start of the global challenge for reaching the UN Sustainable Development Goals (SDGs) [1]. While there is no doubt that the Millennium Development Goals (MDGs) accelerated progress in fighting hunger and malnutrition between 2000 and 2015, the major threat to food security in the SDG-era is expected to be reinforced by population growth and adverse climatic changes [2, 3]. While increasing food production as such is often considered as a key solution, it comes at a high cost i.e. utilizing the already scarce resources such as clean water, land, protected areas and forests, that are necessary for a healthy environment and biodiversity [4, 5]. Since one-third of food produced is lost or wasted along the supply chain [6], dedicated efforts ought to be directed toward the implementation of innovative measures from farm to fork, thereby not only ensuring the delivery of significant quantities of food, but also retaining the level of nutrients in those foods [7]. In this context, literature distinguishes "food losses", a decrease in edible food mass occurring during production, postharvest and processing, from "food wastes", any raw or cooked food mass that is discarded at retail and consumption [8-11]. Together, they are defined as "food supply chain losses", referring to each stage along the chain where a given proportion of food that is initially meant for consumption does not reach the intended consumer [12].

From an economic point of view, initiatives that tackle food losses and wastes (FLW) are not only beneficial to those food producers aiming to sell more, but also to consumers who could save money as the available food becomes more affordable [13], and enhance their energy and nutrient intake, when also quality losses in food would be addressed [14-16]. For example, there is evidence that addressing FLW in developed countries can significantly reduce food prices in developing regions, save resources that can be used to feed a hungry population and boost efficiency along their supply chains [17, 18]. Although such changes are said to potentially improve accessibility to nutritious foods among vulnerable households [6, 19], there is need to better address food and nutrition losses or wastes simultaneously in order to reach some of the SDGs. First of all, perishable products that are highly nutritious, such as vegetables, fruits, diary, meat and fish, are often more prone to loss and wastage along the supply chain than staple foods, like cereals [20]. Post-harvest losses in such foods are singled out as a factor that affects availability and accessibility to poor individuals [21]. Second, through reducing weight or size of edible parts of plants or animals, an estimated 25% loss of available calories eventually are not consumed [22]. Thereby, food processing activities such as inappropriate peeling and cutting are known to not only lead to quantitative food losses and wastes, but also compromise the micronutrient quality [23, 24]. Vitamin C and A, for example, are easily lost in fresh cut fruits as compared to whole fruits due to the processing operations [25, 26]. As such, this approach of tackling both food and nutrition losses, can reinforce agriculture-nutrition linkages and ultimately contribute to food and nutrition security [27]. When half of the FLW along the supply chain would be reduced, about 63 million undernourished people from developing regions would be saved [28].

To eliminate waste along the food supply chain, lean manufacturing, initially developed as a quality management tool for the identification and removal of non-value adding activities (waste) in the automobile sector, has been increasingly applied in the agri-food industry [29, 30]. As such, lean philosophy can hence be considered as a gateway to a systems thinking that requires collaboration of all value chain actors [31]. Nevertheless, its penetration into the agricultural sector has been slow and this has been attributed to the perishability of a wide range of food products, complexity of the agri-food supply chain and dynamic consumer preferences [32]. Regardless of the fact that not all lean tools can be easily adapted to a new processing industry, Value Stream Mapping (VSM), where wastes (i.e. seven "Lean" wastes [33]) are identified through the development of a current and, through the application of other lean tools, a future state value stream map [34, 35], has found its way into the agri-food industry [36]. Its success has been shown in its ability to improve the effectiveness of value chain analysis by enhancing consumer value at each stage [37], boost food production and service [38], minimize wastes in convenience food manufacture [39] and improve efficiency of a food contract manufacturer [40]. Although previous studies justify its use in various industries as a tool to carb waste, none to the best of our knowledge has explicitly explored its adaptability to FLW with a specific link to nutritional benefits yet the potential exists.

Based on a systematic review approach, this study is considered the first to aggregate and examine evidence on the application of VSM in the agri-food industry. Thereby, specific attention will be devoted to the potential of VSM to be combined with other methods targeting the elimination of food waste, as well as its adaptability for measuring nutrition losses and waste.

Methods

Search strategy

Studies were identified by searching ISI Web of Science for peer reviewed articles, AgEcon and google scholar databases for working papers deemed relevant in order to broaden the scope of the review. Although there are challenges of incorporating literature from non-indexed journals, using such an approach as an exclusion criterion has also been criticised elsewhere [41]. The search syntax used included the following search terms referring to lean and VSM (value stream mapping, lean manufacturing, lean management, lean philosophy, lean thinking, lean principles, lean practices and lean tools), combined with food related terms (food, food supply chain, agri-food chain, food industry, food sector and agriculture). For confirmatory purposes and to identify additional studies, a reference list of a recent review on adoption of Lean principles [36] was also utilized. The search for articles was done in December 2015 by two researchers, cross-checking each other at every search step as a control.

Study selection

The inclusion criteria used for selection of relevant studies was initially based on title and abstract screening to ascertain the existence of both lean and food related key words (**Figure 1**). After the removal of doubles, a full paper review was performed where a more stringent inclusion criteria was applied. Studies that utilized VSM as (one of) the lean tool(s) were retained to constitute the systematic review. Further a study had to focus on at least one supply chain actor i.e. primary producers, processors, distributors, food service and/or consumers. There was no restriction applied on whether a study aimed at the identification and elimination of wastes. Studies that did not explicitly examine this were included, as they still applied VSM with elements that can be related to waste identification and elimination, which further enlarged the scope of the current review. Manuals, editorials and commentaries were disregarded.

Data extraction

A data extraction sheet was designed and used to systematically record and code necessary data from the studies. We extracted information related to; level of analysis, targeted supply chain actor, type of food product, country, year of publication, study design, method of data collection, application of VSM (state maps, lean metrics, other lean tools and use of simulation), type of- and reason for- waste. With regards to lean metrics (e.g. lead time, takt time and number of operators), the performance improvement was calculated based on the difference between the current and future state, and expressed in terms of a percentage reduction in a given metric [32]. These elements facilitated the formulation of a comprehensive narrative with an overview of selected studies with respect to their characteristics, application of VSM and the reported food and nutrition losses/wastes.

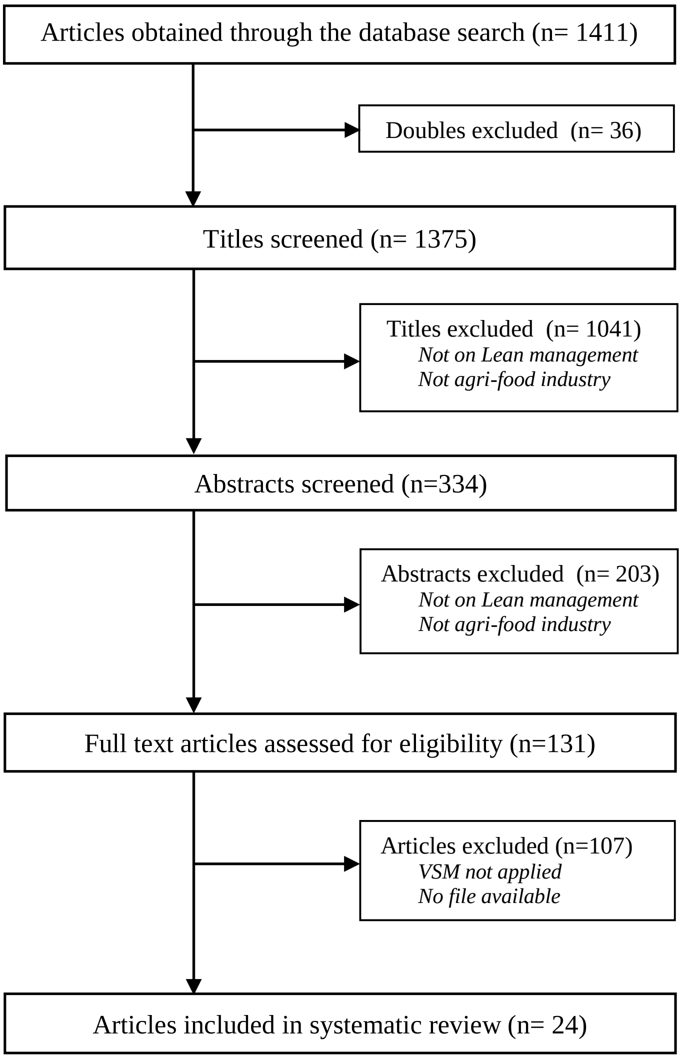

Figure 1: Flow chart of search and selection of studies applying VSM in agri-food industry

Results

Study characteristics

As the flow chart (**Figure 1**) illustrates, the search initially identified 1411 studies that were of potential relevance. However after removing doubles, title, abstract and full article screening, a total of 24 studies were selected, classified based on the number of supply chain actors (**Table 1**). All studies were published from 2003 onwards, using a case-study approach to collect data from interviews, focus groups, observations and records or a combination. Among High Income countries, most studies (8/14) were conducted in United Kingdom, mainly attributed to the development of a Food Value Chain Analysis methodology (FVCA) based on lean philosophy, which was commissioned by the government and implemented in various agri-food sectors from 2002 [42]. Among Low Income countries, India had three studies more than others, but of particular importance, at least one study originated from Asia and Africa.

Of the 24 studies, 19 applied VSM in a single agri-food plant setting, of which 15 focused on a food processing company, producing; bread [43, 44], ready to eat foods [39, 45], peaches [46], wine [47], mango juice [48], ketchup [40], yogurt [49], biscuit [50, 51], coffee [52], snacks [53], nougat [54] or tea [55]. Furthermore, studies on single chain members targeted the food service sector, i.e. two hospital kitchens delivering a variety of foods such as bread, soups and processed vegetables [38, 56] versus fast food restaurants [57], or a food warehouse [58]. Five studies have analysed more than one actor along the food chain. While the study by Francis et al [59] examined a beef producing farm and processing factory, four other studies also included a retailer, e.g. in a chain producing lamb [60] and pork [61, 62], or both wholesaler and retailer, i.e. in an edible oil supply chain [63].

Application of VSM, additional lean tools and performance indicators

With regard to application of VSM in a given agri-food context **(Table 1)**, majority of studies used a mapping technique and developed both current and future state maps i.e. ten studies at the single plant level [44, 46-48, 51-54, 57, 58] and two studies at the supply chain level [61, 63]. Although state maps were in general graphically illustrated, two additional studies [43, 56] only described the current and future states. There were six [38-40, 45, 49, 55] and three [59, 60, 62] studies that only used the current state map at a single and supply chain level, respectively, well as one study [50] gave a description of the current situation.

Except for three studies [46, 61, 63], all case-studies with both maps used lead time, takt time and/or number of operators as lean management metrics to calculate performance improvements in food production processes. At a single plant level, comparison between current and future situations resulted in a reduction of 3%-83% (lead time), 2% (takt time) and 7%-40% (number of operators) among processors and a reduction of 83% and 75% in lead time at storage and consumption, respectively. A reduction of 93% in lead time was illustrated by one study at the supply chain level [63]. Among those studies that included only current state mapping, four reported an associated lead time [39, 40, 55, 62], one cycle time [60] while four studies reported none [38, 45, 49, 59]. Finally, only one study [50] did not report any lean management metric.

With regard to continuous improvement (i.e. Kaizen), a requirement for achieving objectives in lean management, a number of additional tools were utilized either alone or in combination in various agri-food entities. Just-In-Time (JIT) or pull strategy was the most applied alongside VSM in nine studies [39, 46-48, 51, 54, 55, 61, 62] at both levels of analysis. 5S (sort, set in order, shine, standardize and sustain) methodology was mainly used in six studies [43, 45, 47, 48, 56, 58] at a single plant level only. Other lean tools used included Kanban [47, 51], visual aids [40, 59] and cellular manufacturing involving a reorganisation of fast food restaurants based to two distinct customer needs [57]. While all studies adopted the VSM approach and associated tools to some extent, five studies also integrated a simulation modelling technique in their analyses [39, 50, 52-54].

Table 1: Overview of key characteristics and performance of case-studies applying Value Stream Mapping, classified by level of analysis

Level of analysis	Chain actor	Entity	Type of food	Country	Year	Method of data collection	Application of VSM				Reference
							State maps	*Other tools*[a]	*Lean metric*[b]	*Reduction*	
Single Plant level	Processor	Food factory	Bread	United Kingdom	2013	Interview & observation	Current & future*	5S	Lead time	49%	[43]
									Operators	33%-40%	
				Zimbabwe	2011	Interview & observation	Current & future	-	Lead time	25%	[44]
			Ready to eat foods	United Kingdom	2006	Interview	Current	JIT	Lead time	*ND*	[39]
								Simulation			
					2013	Observation & records	Current	5S	-	*ND*	[45]
			Peaches	Greece	2015	Interview & records	Current & future	JIT	Lead time	*ND*	[46]
									Operators	*ND*	
			Wine	Spain	2012	Not mentioned	Current & future	5S	Lead time	63%	[47]
								JIT			
								Kanban			
			Mango juice	Bangladesh	2015	Not mentioned	Current & future	5S	Lead time	55%	[48]
								JIT	Takt time	2%	
									Operators	32%	
			Ketchup	Finland	2005	Interview & observation	Current	Visual aids	Lead time	*ND*	[40]
			Yogurt	United Kingdom	2008	Interview & observation	Current	-	-	*ND*	[49]
			Biscuit	Saudi Arabia	2013	Not mentioned	Current*	Simulation	-	*ND*	[50]
				India	2012	Observation	Current & future	JIT	Lead time	15%	[51]
								Kanban	Operators	7%	
			Coffee	Thailand	2014	Not mentioned	Current & future	Simulation	Operators	13%	[52]
			Snacks	Malaysia	2015	Observation	Current & future	Simulation	Lead time	3%	[53]
			Nougat	Uruguay	2013	Observation	Current & future	JIT	Lead time	83%	[54]
								Simulation			
			Tea	United Kingdom India	2015	Interview, observation & records	Current	JIT	Lead time	*ND*	[55]
	Storage	Food warehouse	Variety	United States	2014	Observation	Current & future	5S	Lead time	83%	[58]
	Consumer	Hospital kitchen	Variety	United Kingdom	2015	Interview & focus group	Current	-	-	*ND*	[38]
			Variety	Denmark	2009	Interview & observation	Current & future*	5S	Operators	24%	[56]
		Food restaurant	Fast foods	Iran	2009	Interview	Current & future	Cellular Manufacturing	Lead time	75%	[57]
Supply chain level	Farmer Processor	Farm Food factory	Beef	United Kingdom Argentina	2008	Observation	Current	Visual aids	-	*ND*	[59]
	Farmer	Farm	Edible oil	India	2008	Interview & observation	Current & future	-	Lead time	93%	[63]
	Processor	Food factory	Lamb	United Kingdom	2003	Interview & observation	Current	-	Cycle time	*ND*	[60]
	Sale Point	Wholesale/retailer	Pork	United Kingdom	2005	Interview & observation	Current & future	JIT	Lead time	*ND*	[61]
					2006	Interview & observation	Current	JIT	Lead time	*ND*	[62]

[a] Tools applied alongside VSM. 5S refers to efforts meant to facilitate the flow of materials and people in the work area; JIT (Just-In-Time) are practices related to pull strategy aiming at producing according to demand; Kanban is a signaling system used for inventory control and efficient product flow; Cellular manufacturing means producing similar products using grouped resources; Simulations refers to designing statistics-based models that mimic reality to generate a better understanding of a process.

[b] Lean metrics represent performance indicators. Lead time refers to the time it takes for one unit of a product being transformed to go through every process of the entire value stream; Takt time represents the rate at which completed products reach consumers in line with existing demand; Cycle time is the average time it takes to complete one unit from the start to the end of a process; Operators represents the number of individuals needed to perform a process task.

ND No Data; Missing either current and/or future lean metric data.

* No visual mapping included in study.

Identification of waste

Out of the twenty four studies reviewed, twenty referred to waste identification and/or elimination, e.g. susceptible supply chain hot spots, type of waste/loss (including a categorization based on the seven Lean wastes) and the specific reason(s) behind the identified wastes/losses (**Table 2)**. Two types of wastes/losses became evident i.e. discard waste in all studies while nutrient losses potentially occurred in two studies. As such both could be attributed to comparatively similar lean wastes at a particular supply chain hot spot i.e. primary production, processing, storage and food service/consumption.

Defects in product

This lean waste was present at all four supply chain hot spots and was associated with discarded food. In a study analysing a pork chain, incorrect weight and fat levels at primary production were considered as product defects [61].

Similarly, defects in food processing companies arose from poor/overtopping, over baking, variation in size and shape [43] and breakages [44] in the production of bread, scrap or poor quality in peach [46], biscuit [50, 51], pork [61, 62] wine [47], tea [55] and edible oil [63] production. Further, microbial spoilage associated with short shelf life as a defect at processing resulted from; repetitive handling by operators [39, 49, 59], contact with contaminated surfaces [59] and cooling at a slow rate [49].

Defects also occurred during storage in a study where food was exposed to ambient temperature for prolonged periods [58]. At food service, wrong meal service in hospital kitchens [38] and mismatch of customized needs of consumers at fast food restaurants constitute defects [57]. In addition to discarding overbaked products in a study involving bread manufacture [43], it is more likely that heat labile micronutrients were also lost.

Unnecessary inventory

At farm level, unused inventory could be disposed-off as waste culminating from uncertain supply of raw materials used to produce edible oil [63], and the use of a push system in production of pork [61, 62]. This was more or less similar in food processing companies in situations where; there was accumulation of either raw materials or finished products than needed [40, 50, 61], excess stock was meant to act as a buffer against poor quality products [47], purchase of raw materials in small quantities was either impossible [54] or they remained unused [51].

Over production

As a lean waste, overproduction was evident during food processing and food service for relatively similar reasons i.e. misalignment of production with consumer demand of ready to eat foods [39] and poor demand forecast where food was usually produced without orders in a hospital kitchen respectively [56]. Consequently, excess food could be thrown away.

Inappropriate processing

Mainly during food processing in three studies, did this waste occur encompassing incorrect topping, overbaking and unstandardized slicing [43], poor timing of slicing operation [44] and incorrect forming with loss processing materials (frying oil and crumbs) [45]. The nutrient losses that could occur at this stage were mainly due to overbaking of bread [43], inappropriate peeling, washing and pasteurization of peaches [46].

Table 2: Hot spots and wastes and their causes derived from agri-food studies applying Value Stream Mapping, split up according to stage

Hot spot	Form of loss/waste	Lean waste	Cause of waste	Ref
Primary production	Discard	Unnecessary inventory	Uncertainty in supply of raw material	[63]
			Use of push production system	[61, 62]
		Defect in product	Non-conformance to specifications[a]	[61]
Processing	Discard	Defect in product	Non-conformance to specifications[a]	[43, 44, 46, 47, 50, 51, 55, 61-63]
			Short shelf-life due to microbial spoilage	[39, 49, 59]
		Inappropriate processing	Poor & over topping, overbaking, variation in size/shape	[43]
			Poor timing of slicing operation	[44]
			Food loss due to forming and loss of processing materials	[45]
		Over production	Poor demand forecast	[39, 50]
		Unnecessary inventory	Excess stock of either raw materials or finished products	[40, 47, 50, 51, 54, 61]
	Nutrient loss	Defect in product	Non-conformance to specifications[a]	[43]
		Inappropriate processing	Overbaking	[43]
			Inappropriate peeling, washing and pasteurization	[46]
Storage	Discard	Defect in product	Short shelf life due to microbial spoilage	[58]
Foodservice/Consumption	Discard	Defect in product	Wrong meal service	[38]
			Mismatch with customized needs of consumers	[57]
		Overproduction	Poor demand forecast	[56]

[a] Including: incorrect weight and fat levels, poor/overtopped products, variation in size/shape, breakages, scrap and/or poor quality

Discussion

In search for innovative measures against food losses and wastes, hence minimize the dependency on costly efforts to increase food production, our review demonstrates a mix of countries where the applicability of Value Stream Mapping in the agri-food industry has been examined. Its use is not limited to developed countries, which gives an indication that such lean management practices can be successfully adopted in different settings, especially because FLW are also present in developing countries [64]. While the majority of studies were conducted at a single plant level, there is a growing interest of analysing FLW through applying VSM at supply chain level. These multi-level studies confirm the presence of hot spots from farm to fork. In other words, tackling FLW requires an all-inclusive mitigation approach, which was also recommended by the Food and Agricultural Organisation [9]. This is further supported by the fact that FLW occurring at one point are often initiated at a preceding stage(s) of the supply chain [65], while the underlying causes of such losses were often present at various levels, regardless of the targeted food product or region [18]. Therefore, from an analytical point of view, a multi-stakeholder approach is needed to involve key actors to examine losses and wastes, as well as determine and evaluate industry-driven mitigation measures [31, 66]. Regardless of possible differences in study characteristics (e.g. timing, data collection method), the current review further illustrates that VSM is adaptable to a wide range of food products likely to be lost or wasted at different stages of the chain, in line with previous studies [10].

In order to realise the benefits attributed to applying VSM as an approach to identify and eliminate wastes, there is need to adequately use validated tools associated with this methodology [67]. While both current and future state maps should form a basis for successfully using VSM [68], not all studies apply them as recommended. In theory, states maps should facilitate the assessment and quantification of performance indicators in order to justify lean implementation. However, our findings show the difficulty practitioners face to elucidate the impact of lean practices if only the current state map or no map is included i.e. failure to satisfactorily illustrate performance improvements. Regarding the use of lean metrics, lead time was the most applied performance indicator accompanying VSM in Lean manufacturing. A reduction in lead time, when both current and future states were compared, fosters satisfaction of customer needs through quicker supply responses to demand of a given product. This is in line with De Treville et al [69] who shows improved performance of demand chains with actors gaining better competitive capabilities in markets when lead time is lowered. This is of particularly importance in agri-food industry mostly characterized by perishable food products which need to be delivered to the consumer at a considerable level of freshness lest be discarded as waste [70, 71]. Likewise, a production process with waiting moments where no value added activity is taking place indicates the need to reduce or divert resources used to other value adding processes in order to save costs i.e. reduction in the number of operators, previously identified as an important component of activity costs [72], can lower production costs as well as still improve production efficiency. With respect to assertions previous made on challenges faced when applying lean tools in a non-discrete agri-food sector [36], based on our findings, there is a high compatibility between VSM and other lean techniques (particularly JIT and 5S applied in most studies) that are applied concurrently. These strategies are indeed relevant to boost continuous improvement in the agri-food industry.

As a complementary tool to VSM, simulation was sometimes used to address the apparent need for justifiable and practical evidence, hence further enhance the potential adoption of lean practices. Indeed, these studies were successful in statistically predicting various future states so as to facilitate the process of making decisions toward adoption of lean practices. Consequently, prospective but sceptic lean implementers can assess the desired impact by determining improvements in performance of their production activities in a dynamic rather than static way [73, 74]. In this context, simulation can be readily applied in the agri-food industry which is characterised by unique and complex factors that currently often hinder the adoption of lean manufacturing practices [32]. Thus, future research in agri-food industry should prioritize investigation that target ways in which simulation models can be reliably incorporated into VSM methodology.

Two forms of wastes and associated causes related to food and nutrition were identified. Thereby, discarded food is mainly attributed to defects, inappropriate processing, unnecessary inventory and overproduction waste categories as described in lean management. Consequently, the association between non-conformance to specifications and defects in food products is explicitly highlighted in the agri-food industry. In concurrence with previous studies [31, 65, 66], various forms of avoidable FLW that occur along the supply chain are particularly explained by failure of discarded food products to match specific quality standards i.e. deviations in size, weight, shape, breakages and shortened shelf life due to microbial contamination similar to our findings. Furthermore, activities performed during processing of food ably cause losses and wastes especially if operations and equipment used are not standardized [10, 75]. This points to a need to introduce process controls not only during internal processing but also extend them to other supply chain operations in order to achieve a holistic reduction of waste [76]. Having excess food stock or preparing too much food than needed due to poor demand forecast is also highlighted as a growing and major source of food waste in both developed and developing countries [18, 77]. In lean manufacturing, pull strategy that underlies Just-In-Time production principle facilitates the initiation of a production process based on existing demand, which in turn prevents overproduction and accumulation of inventory [78, 79]. As such, food producers as well as other chain actors should be encouraged to coordinate and focus on gaining critical awareness of consumer behaviour, needs and preferences beforehand, so as to reliably predict food demand among target markets as Taylor and Fearne [80] suggest. This and other food surplus management practices such as donation for food aid can contribute toward the fight against food insecurity [81]. Likewise in food service industry, a previous study [82], emphasized the importance of creating awareness among staff and customers about causes of food waste and possible mitigation approaches, which further highlights the need to consider consumer level as part of the supply chain.

Food processing techniques may have a profound effect on the nutrient content of food and instances when heat treatment is applied to food products were underpinned in the findings i.e. overbaking and pasteurization may result into loss of thermal labile micronutrients. Previous studies show that nutrients such as thiamine, vitamin A and C are lost not only when excessive heat is applied [83] but also with modest heat treatments in the right combination of oxygen, light and pH [84]. Other physical processing practices involving cutting, peeling, milling and more so if accompanied by washing also potentially result into micronutrient losses [23, 85]. This implies that VSM could not only be effective at identifying FLW but also nutritional losses. Hence, research in agri-food industry should also consider development of innovative strategies and methodologies that integrate both types of losses along the supply chain, as the current evidence shows that both kinds of losses could be attributed to the similar causes.

Only case-studies with at least one food product and type of supply chain actor were included in the systematic review. Although this may be a threat to the generalizability of results to other contexts, the lean practice i.e. VSM which is the focus of this review suits a case study design, because it enables a deeper understanding of the current state of affairs of a production process through a combination of qualitative and quantitative methods, in order to conceptualise a future improved state. Still, the current results as explained in preceding sections and other strengths inherent to the review justify the importance of this piece of work. First is use of an approach that can depict that FLW occur along the entire supply chain. There are few studies that have been conducted empirically from farm to fork, most previous studies although mention the need to tackle this problem in holistic way as such, they fail to move from the rhetoric. The current review, by illustrating that FLW actually occur along the entire supply chain, strengthens both the potential and need to tackle them using a multi-stakeholder approach. A second strength concerns establishing possible links between nutritional value with FLW. There is hardly any study with a clear explanation of such associations and so VSM potentially addresses weaknesses previously highlighted in food loss and wastage assessment methods [86], through careful identification and mapping of hots spots where losses occur along the supply chain, and ensure a novel integration of both quantity and quality loss assessments.

To conclude, although lean implementation in the agri-food industry is still growing, the potential of VSM has been clearly illustrated in the review. Regardless of the challenges of identification and quantification of food losses and wastes along the supply chain, VSM has shown to improve the visibility of the entire value stream (i.e. identification of food loss hot spots) and consequently creates an opening for information sharing that is necessary to reduce FLW in an integrated food system (i.e. multi-stakeholder approach). These findings have wider implications with regards to efforts employed to improve food and nutrition security in the context of minimizing FLW. First, this approach could be a way to increase the quantity of food, made available without expanding food production per se. Second, such lean practices inherently improve production efficiency and through reduction of production costs, prices of nutritious foods could go down in favour of the vulnerable and hungry population. Furthermore, identification of hot spots where nutrient losses occur is a gateway to targeted value chain approaches for nutrition benefits so as to ensure that nutrient retention is upheld as much as possible at all stages of the food supply chain. This review therefore offers innovative insights for future scientific research and policy practice to extend the application knowledge of VSM as an unexplored and complementary approach, with potential to sustainably enhance both food and nutrition security through minimising FLW, rather than only focusing on increasing food production.

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