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Food Chain Transparency for Food Loss and Waste Surveillance

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Food loss and waste is becoming one of the ultimate food system challenges and, therefore, is a topic of growing interest worldwide. Many approaches and methods have been suggested to prevent or reduce food loss and waste. This paper describes an approach to monitor and prevent or reduce food loss and waste by using a food chain transparency framework. Food chain transparency requires a comprehensive and integrated ***farm-to-table*** approach; it implies that all stakeholders (the producer, processor, transporter, vendor, and consumer) play a vital role in ensuring the reduction of loss and waste. Essential information in a food supply chain needs to be adequately recorded and provided for all stakeholders in the chain to promote transparency and to enable the surveillance of food loss and waste. With this systemized transparency, each of stakeholders in food production and consumption understands the relevant aspects of products, processes, and process environments supporting well-informed decision-making. The need for food chain transparency is very critical, particularly because food is a very vulnerable to depreciation of quality and quantity if not well taken care of. This paper addresses the motivation, problems and complexities; current *state of the art*; application practices; research needs; and the future research framework and initiatives in food chain transparency. Our research on a cattle identification and registration system and traceability systems for the production chains of frozen loin tuna and frozen shrimp in the digital business system is discussed to provide more insights on the state of the art and examples of implementation of food chain transparency systems.

Key words: CBIS, food chain transparency, food loss, food waste, surveillance

Introduction

In agroindustry, products are processed in a chain that starts from farmers and extends to consumers (from farm to table). In such a food chain, loss and waste can occur either within the nodes or during transition between the nodes and is likely to propagate along the food chain, thus further increasing food loss and waste (Kantor *et al*., 1997).

A traceability system in a food supply chain is defined as documented identification of the operations that lead to the production and sale of the final product. Its objective is to identify the actors involved, trace relevant flows, characterize the material, its processing, and management operations (Bertolini *et al*., 2006). Food chain transparency requires a comprehensive and integrated ***farm-to-table*** approach, in which the producer, processor, transporter, vendor, and consumer all play a vital role in ensuring food safety and quality and preventing food loss. This can be achieved if everybody with stakes and interest in the food supply chain understands the relevant aspects of products, processes, and process environments that allow informed decisions (Schiefer and Deiters, 2013).

The reduction of food loss and waste across the entire food chain is a key element in increasing the efficiency of our food systems. This aim can be achieved by developing a systematic and integrated traceability

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Table 1. Definitions of food loss and food waste (Thyberg, 2015).

Term	Definition	Drivers	Sectors Included	Examples
Food loss	Decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption	• Infrastructure limitations • Climate and environmental factors • Quality, aesthetic, or safety standards	Production, postharvest, and processing	• Edible crops left in the field • Food spoiled because of poor transportation • Food contaminated during food processing
Food waste	Food that was originally produced for human consumption but was discarded or was not consumed by humans. Includes food spoiled prior to disposal and food that was still edible when thrown away	• Decisions made by consumers and businesses • Quality, aesthetic, or safety standards	Retail and consumer	• Plate waste • Food spoiled because of poor storage • Restaurant food prepared but discarded because of lack of demand

system embedded in the food chain. This paper describes the use of a food chain transparency framework to monitor and reduce or prevent food loss and waste.

Critical factors affecting food loss and waste

Because the terms "food loss" and "food waste" are often used interchangeably, it is important to distinguish them on the basis of the definitions listed in Table 1.

According to Kantor *et al*. (1997), Gustavsson *et al*. (2011), and Thyberg (2015), food loss and food waste can occur due to several factors described in Table 2.

Motivations for surveillance of food and waste

Food loss and waste surveillance is increasingly critical to ensure sustainable food production under the increasing of world population and food consumption and the decreasing of the carrying capacity of nature. A study conducted by Food and Agriculture Organization (FAO) estimated that one-third (about 1.3 billion tons per year) of all food produced for human consumption is lost or wasted (Gustavsson *et al*., 2011). The drive to address food loss and waste stems from increasing concerns about hunger, resource conservation, the environmental and economic costs of food loss and waste, and a general trend in the waste management industry toward more sustainable practices. Therefore, reducing food loss and waste can help achieve socially, environmentally, and economically sustainable food systems (Thyberg, 2015). A surveillance system helps to improve precision and accuracy of food production systems with minimal undesirable social, environmental, and economic impacts. A surveillance system should enable quick and precise quantification of food loss and waste in a very transparent and systematic way.

Approaches to food loss and food waste surveillance

One of the approaches to food loss and waste surveillance is the use of a transparency framework (Schiefer and Deiters, 2013). In a food supply chain, essential information needs to be adequately recorded and for all stakeholders in the chain to allow traceability and to promote transparency along the chain. In food production, different food chains may form a network that stretches from farmers to consumers (Fig. 1). In addition, the complexity of the network is further characterized by its global orientation, which varies depending on cultural, political, and geographical backgrounds, social and religious values, preferences, diets, and prestige.

A framework of food chain has been developed by Barnard (2006), Schiefer and Deiters (2013), Min

Table 2. Factors that affect food loss and waste.

Process	Stages in the Food Chain	Factors
Food loss	On-farm and harvest	Severe weather, disease, insects, and predation
		Poor on-farm processing systems
		Poor production practices
	Off-farm processing and wholesaling	Removal of inedible portions (e.g., bones, blood, peel, pits)
		Disposal of substandard products (e.g., bruised fruit)
		Damage and shrinkage in storage
		Poor handling or package failure
		Transportation losses
Food waste	Off-farm processing and wholesaling	Poor off-farm processing
		Poor transportation or packaging failure
		Food disposal because of insufficient quality, out-grading, damaged packaging, expiration date
		Food overstocking
		Excess food purchased but not consumed or sold (either at the consumer or retail level)

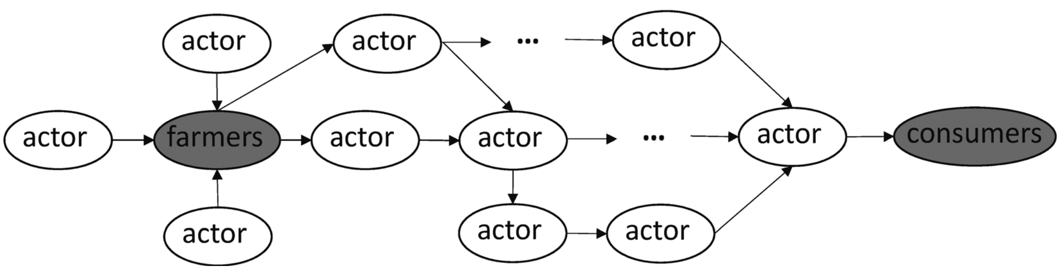

Fig. 1. Network of food value chain from farmers to consumers.

(2004), and Yu (2012). The methods and tools for monitoring and quantifying food loss and waste have been developed by Bertolini *et al*. (2006), Danan *et al*. (2011), Kantor *et al*. (1997), Kresna (2014), Beretta *et al*. (2013), and Thyberg (2015). Information technology (IT) mediated transparency methods have been developed by Bernard (2010), Seminar *et al*. (2010), Schiefer and Deiters (2013), and Ginantaka (2015).

A computer-based information system for food chain transparency

To serve the needs of food chain transparency, a computer-based information system (CBIS) comprising hardware, software, dataware, netware, infoware, and brainware resources must be established to transform data into information along the food chain. The CBIS can enable the achievement of transparency and surveillance goals in food production, delivery, and consumption (Fig. 2).

The hardware resources include sensing devices, data loggers, data scanners, communication devices, data storage, information displays, actuators, processing units (microprocessors), computers, smartphones, and communication devices. The software resources include: operating systems and related applications; database management system software; geographic

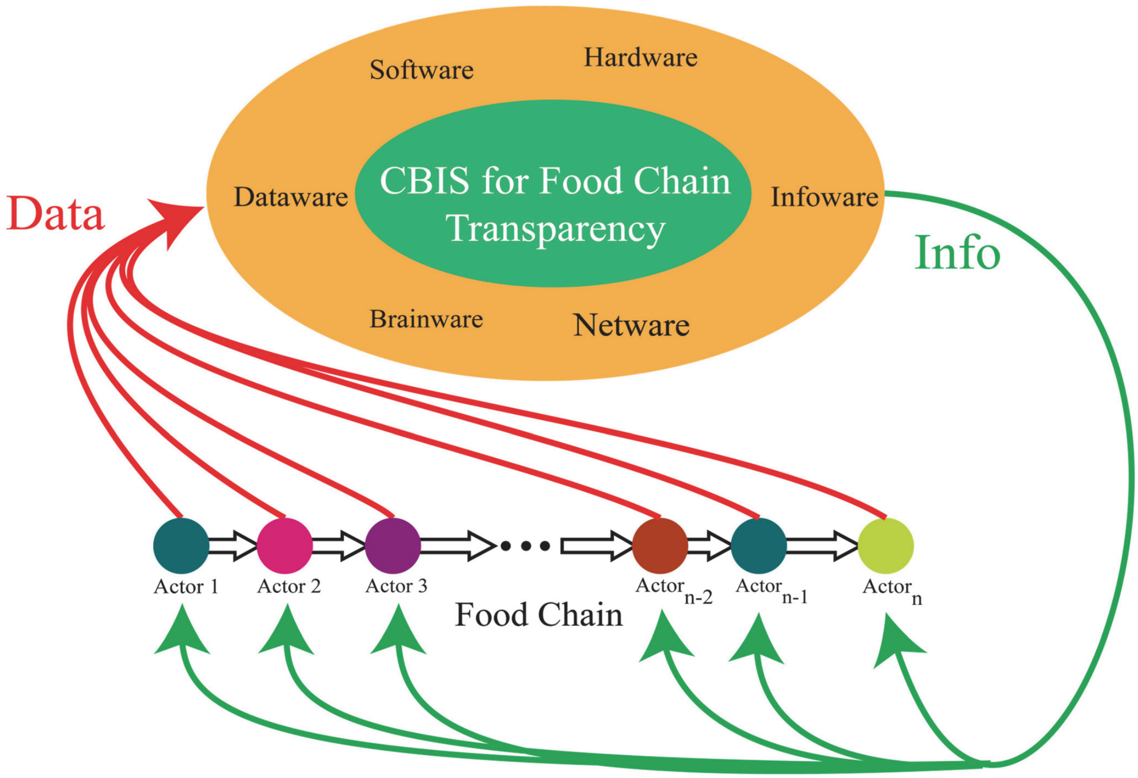

Fig. 2. The CBIS for food chain transparency.

information system (GIS) software; data acquisition, analysis, and reporting software; specialized applications (such as knowledge management, enterprise resource planning, decision support, and customer relations management systems); and search engines for information retrieval.

The dataware resources include all data (historical, real-time, statistical, spatial, and geographical) related to any nodes (actors), processes (activities), events, food products, and quality standards. The netware resources include network access and control, communication media, site directories, communication processors, web services, and technology network clusters (intranet, extranet, and internet). The information resources include (in a digital or printed form) operational and managerial reports, forecast and trend analysis reports, early warning signals, and decision scenarios and options. The brainware resources include all actors involved in the food chain and CBIS, such as database administrators, chief information officers, management information system managers, subject-matter experts and specialists, and end users.

Importantly, the CBIS supports (1) various algorithmic, programmable computational scenarios; (2) real-time, objective, and precise data acquisition from any nodes (actors) of the food flow at any stage; (3) storage of massive amounts of graphical, spatial, temporal, statistical, and serial data (in the form of text, video, and audio) related to processes, objects, and actors; and (4) linking, tracing, and unifying all actors at different stages, geographical areas, and time zones.

The increased diversity of products, processes, information, or actors increases the need for diverse services of transparency (Schiefer and Deiters, 2013). Therefore, there is also a need for diverse resources of CBIS to support the surveillance of food loss and waste.

State of the art in food chain transparency and traceability

A CBIS model for cow identification and registration has been developed (Seminar *et al*., 2010). This system can be used as part of a transparency system in the beef supply chain from breeding units to retailers and consumers. Every cow that has been delivered or imported from abroad is identified and registered in the system; all critical information about the cow can then be acquired at various stages of the supply chain for traceability purposes. In the proposed system, the data can be captured with various input devices (such as RFID sensors, cow muzzle print sensors, ear tag sensors, GPS microchips and electronic collars, brand and tattoo sensors). Some sensors can store particular sets of data about individual cows including the date of birth and birth weight, pedigree, health history, size, ownership, movement history, and skin or fur color. Remote data acquisition and delivery can also be done using mobile devices such as hand phones via short message service (SMS) or multimedia message service (MMS), or via web access facilities. The proposed system has been extended and integrated into the *e-livestock* framework in Indonesia (Ramadhan, 2013). Although a prototype system for CBIS-based cow identification and registration was proposed to the Ministry of Agriculture of Indonesia, a full version was not implemented.

A laboratory-based surveillance system for isolation of *Salmonella* in the food chain was integrated into the French Food Safety Agency's working plan (Danan *et al*., 2011). This early warning system used statistical methods to detect unusual events of *Salmonella* contamination as early as possible. During an experimental period (＞1 year), several such events were detected and confirmed promptly at the national or regional level. This evaluation also reinforced the position of the *Salmonella* network as an integral part of the national public health surveillance system. The current shortcoming is that not all actors in the food chain allow data acquisition, processing, and reporting in an objective, standardized, periodical, accurate, coherent, and timely manner.

Beretta *et al*. (2013) developed a model for the analysis of the energy flow in the food supply chain to quantify food losses (including imported products) in Switzerland. Data collected from the firms (actors) involved in the food value chain are converted into food loss values on the basis of the caloric content of the output expressed as a percentage of that of the input into the corresponding stage. However, the amount of food losses is not suitable as the sole indicator of the potential to reduce food losses. The actors incorporated in the model includes an agricultural production firm, a harvest handling and trade firm, a processing firm, food service industry, retailer, and a private household. The authors applied this model to various food categories including fresh vegetables, bread and pastries, and eggs, and reported that 48% of the total caloric content of the food produced in Switzerland is lost. Half of these losses was inevitable without appropriate mitigation measures. However, the use of CBIS, especially for real-time and periodic data acquisition, in this flow analysis model was not explicitly stated.

On the basis of ISO 28000, Kresna (2014) developed a model to assess implementation of traceability of the frozen loin tuna distribution chain in Indonesia. The model examines three aspects: (1) the security system in the distribution chain; (2) critical risk management in the process of product distribution; and (3) compliance of the distribution process with ISO 28000. The distribution chain stretches from fishing vessels to exporters.

The developed model focuses on food safety, particularly on the histamine level and the content of metal flakes in tuna loin products. The histamine level is measured by using two indicators, total plate count and total volatile base, which can affect the quality and safety of tuna products. The United States Food and Drug Administration (FDA) allows histamine levels of ＜50 ppm. The authors did not specify the use of an integrated CBIS, especially for real-time and periodic data acquisition.

An information system was developed to monitor the chain of frozen Vannamei shrimps distribution in a digital business system that involved several interacting actors (from breeding units to retailers) communicating to achieve a common goal (Ginantaka, 2015). The business process model notation was used as a primary tool to analyze the data flow among traceable units from shrimp breeding companies to retailers. The CBIS developed consists of a data capture and storage function and a data processing and reporting function. The data capture function provides data input facilities that can be used by each actor. However, most of the data capture process still manually entered through a data input interface, except for the bar code data capture. Real-time data capture is not yet implemented in this system. Some of the data sets that must be entered into the traceability system include all pertinent data about shrimps and the processing conditions in each breeding unit, on-growing unit, processing unit, cold storage and retailer involved in the shrimp production chain. The data processing and reporting function provides analytical and reporting tools including data mining, simulation, and prediction.

Conclusion and future directions

This paper has discussed the groundwork to develop a computer-based information system (CBIS) for food chain transparency needed to implement food loss and waste surveillance. The critical importance of and motivation for food chain transparency and traceability has been emphasized. A road map of research work on food loss and waste surveillance has been highlighted to guide future research directions. Several implemented food chain transparency systems have been discussed to reveal some implementation issues and the use of CBIS to support the systems.

Although many systems have been proposed and developed for implementation of food chain transparency, only a few have emphasized the use of CBIS for real-time data acquisition. Therefore, the use of wireless sensors for real-time data acquisition needs to be explored. Because of the nature and complexity of a food chain that involves diverse and dispersed actors and resources, the use of emerging technologies (such as cloud, ubiquitous, mobile, intelligent, and distributed computing technologies) is worth pursuing. Whereas this paper has focused on the technological perspectives, supplementing institutional, policy, social, and cultural behavior should receive more attention to ensure the implementation and best practices in food chain transparency for food sovereignty and security, and reduction of food loss and waste.

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