Global Challenges in Focus

Innovative Technologies Tackling Food Loss

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Introduction

A large part of food produced is being lost or wasted. A commonly cited figure from 2011 indicates this to be as much as 1.3 billion tons or roughly one third of globally produced food (FAO 2019b). In response, authorities around the world are prioritizing the reduction of food loss and waste (Xue and Liu 2019). The United States, for example, has a target to halve food waste by 2030 (USDA 2017). The European Union is also taking actions towards this goal (European Commission 2017), and the African Union has made a commitment to halve post-harvest losses by 2025 (Lipinski *et al.* 2016). United Nations Sustainable Development Goal (SDG) 12 calls for global food waste at the retail and consumer levels to be halved by 2030, as well as the reduction of food loss along production and supply chains, including post-harvest losses (UN 2020).

Although the notion of food loss/waste may appear simple, a commonly agreed upon definition does not exist. To address and improve this, the Food and Agriculture Organization (FAO) of the United Nations recently harmonized relevant concepts into a practical definition whereby food loss is "the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food service providers and consumers," and food waste is "the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services and consumers." Food loss, the focus of this paper, was in 2016 estimated to take away around 14 percent of the food produced globally, although with notable regional variations (FAO 2019b).

Tackling food loss and food waste is complex and requires many different solutions (WRI 2019a). Apart from behavioral change, commitment, and the continuous efforts of all involved parties, the application of technological solutions at various stages of the food supply system is instrumental (Galanakis 2019). These include supporting agricultural practices and retailers with modern technologies, optimizing post-harvest techniques, promoting new packaging solutions, valorizing by-products, and ultimately applying innovative processes.

This *Global Challenges in Focus* paper looks at cutting-edge technologies to reduce food loss in the supply chain. We begin by identifying "critical loss points," the points at which food loss has the largest impact across the supply chain, followed by a description of innovative technologies which may help mitigate food loss in each loss point. The paper aims to provide an insight into the technological options currently being developed and deployed across the food supply chain from harvest and up to retail. Innovative technologies available for tackling food waste will be described in a forthcoming paper.

The mention of specific companies or products of manufacturers does not imply that they are endorsed or recommended by WIPO in preference to others of a similar nature that are not mentioned.

The challenge of avoiding food loss: critical loss points

According to a recent study led by the World Resources Institute, food providers and retailers, together with their suppliers, should be able to reduce food loss by up to 50 percent at various critical loss points (WRI 2019a). Subsequently, major food retailers and providers have already joined the New “10x20x30” Food Loss and Waste Initiative where 10 of the world’s largest food retailers each engage with 20 of their priority suppliers with the aim to halve rates of food loss and waste by 2030 (WRI 2019b).

The food supply chain refers to all processes taking place for food to reach the final consumer. The major links in the food supply chain are production, post-production operations, processing, storage and transportation, and finally, consumption. Food loss and waste can occur throughout the chain. In addition, food loss and waste vary considerably among countries and are somewhat related to their level of economic wealth. For instance, in low-income and developing countries, food is primarily lost up to the level of processing, while high-income and developed countries generate large amounts of food waste at the consumption level (FAO 2019b). Nevertheless, food loss and food waste cannot be generalized across the food supply chains, and it is therefore important to identify the critical loss points for targeted supply chains in each setting (FAO 2011; FAO 2019b).

Table 1 presents the most seriously affected critical loss points for different commodities across the food supply chain. Harvesting is a critical loss point for all products, whereas on-farm storage appears to be one particularly for grains, legumes and cereals. Food loss from harvesting and on-farm storage most seriously affects farmers in low-income countries (FAO 2018; WFP 2019; WRI 2019a). Packing and transportation are major critical loss points for fruits, roots and tubers, caused largely by poor handling. For highly perishable foods, specifically fish and animal products, critical loss points have been identified during slaughtering, handling and storage (Diei-Ouadi and Mgawe 2011; FAO 2014; FAO 2019b). In the case of dairy products, sanitation plays an important role as contamination can force farmers to discard entire milk batches. Inappropriate milking equipment and inadequate cold storage are also critical aspects (FAO 2014; FAO 2019a). Since microbial deterioration is accelerated in hot and humid conditions, cold storage of highly perishable foods such as fish and meat is crucial (Fonseca and Vergara 2015). Other foods such as baked goods and cooked products show higher losses during retailing (HLPE 2014). Finally, in low-income countries that lack appropriate facilities and reliable and safe cold chains, processing comprises a critical loss point of highly perishable and seasonal products.

Table 1. Critical loss points for different commodities across the food supply chain

Commodity	Critical loss point	Justification/Causes	Reference
Agricultural production/harvest/slaughter/catch			
All	Harvesting	– Identified in >70% of *Save Food* case studies – Maturity level, time schedule – Lack of proper sorting (for fruits) – Attacks by pests/insects – Diseases and occasional climate conditions (extreme rainfalls, etc.) – Lack of labor or funds – Improper practices capturing inedible fish species (that are typically discharged)	Diei-Ouadi and Mgawe 2011; FAO 2014; FAO 2019a
Cereals, grains and legumes	On-farm storage	– Inadequate storage – Insufficient ventilation – Lack of proper handling	FAO 2019a; WRI 2019a; WFP 2019
Maize	Stocking in the field	– Lack of biological agents (natural predators) in the field – Long stocking period of more than 2 months – Limited labor supply	FAO 2018
Post-harvest/slaughter/catch operations			
Fruits, roots and tubers	Packing	– Poor handling – Inappropriate packaging – Rough packaging – Lack of humidity and temperature monitoring – Mechanical damage	Diei-Ouadi and Mgawe 2011; FAO 2014; FAO 2019a
Processing			
Highly perishable and seasonal products	Food processing	– Lack of proper disinfection – Lack of cold chain in low-income countries	FAO 2011; FAO 2019a
Storage/Transportation			
Fruits, roots and tubers	Transportation	– Poor handling (unclean containers made of inappropriate materials, long-distance) – Inadequate storage conditions – Inappropriate packaging	FAO 2019a; WRI 2019a; WFP 2019
Milk	Storage	– Lack of cooling facilities – Deficient milking equipment – Poor sanitation – Inappropriate handling	FAO 2014; FAO 2019b
Fish, meat and animal products	Storing and transportation	– Poor handling – Cold chain malfunctioning	Diei-Ouadi and Mgawe 2011; FAO 2014; 2019a
Packaging/Wholesale/Retail			
Highly perishable foods	Packaging	– Inadequate protective packaging – Temperature and humidity control	HLPE 2014; FAO 2019a

Technology solutions with high potential

Interventions to tackle food loss should be designed for each case and country separately, as low- and high-income countries typically require different measures (FAO 2019b; WRI 2019a). The food loss causes in the critical loss points shown in Table 1 suggest that developing countries require interventions to address handling and management problems more than insufficient treatment of agricultural products (Martins *et al.* 2019). For instance, smallholder farmers in Africa may lose almost half of their production due to insects or mold growth. In such cases, emphasis should be on training in drying grain safely as well as on using airtight bags and silos for storage (WFP 2019). However, such practices may not be relevant in developed countries or in different climates. Furthermore, poor handling of a product in one stage may cause fast deterioration during the subsequent stage even under optimum conditions (HLPE 2014). For instance, insufficient pasteurization or preservation may lead to losses during storage and transportation.

Table 2 presents innovative technologies with high potential in relation to the above-mentioned critical loss points. Technology-based solutions can provide insight which may optimize harvesting time as well as provide forecasting and early warning of potential stress situations. Food safety can be improved through traceability of contamination, for example, and information and communication technology (ICT) can ensure detailed optimization of handling and management practices on-farm as well as provide solutions during post-harvest operations, storage and transportation (World Bank 2017). Similarly, the Fourth Industrial Revolution or Industry 4.0, a term capturing the ongoing rapid automation of traditional manufacturing and industrial practices, includes a variety of new digital solutions to optimize the entire food value chain, remake manufacturing and production systems, and improve product traceability (Hasnan *et al.* 2018; Martins *et al.* 2019). Technologies enabling cold chain improvements such as superchilling, or moisture conditioning of products such as innovative drying technologies, can reduce food loss during packing, storage and transportation (Rahman and Velez-Ruiz 2007). Non-thermal technologies are also innovative tools in food preservation and pasteurization, while smart, active and biodegradable packaging could reduce food loss during transport and at the retail level (Rosa 2019).

Table 2. Innovative technologies with high solution potential in critical loss points

Critical loss points	Solution needs	Potential technologies
Agricultural production/harvest/slaughter/catch		
Harvesting	– Reschedule harvesting and improved methods – Early warning systems – Collaborative planning and forecasting – Determination of maturity points and harvest time	– Satellite-based early warning systems – Insect warning systems – Geographic Information Systems (GIS), GPS and mobile apps
On-farm storage	– Inadequate storage – Protection of crops from occasional extreme weather conditions – Proper ventilation – Improved storage room/containers	– Improved sensor and monitoring systems – Various forms of improved storage techniques
Stocking in the field	– Usage of biological agents	– Application of bio-predators and/or bio-pesticides
Post-harvest/slaughter/catch operations		
Packing	– Improvement of cold chain – Improved monitoring of humidity and temperature	– Innovative drying methods (e.g., osmotic dehydration, microwave, vacuum and hybrid drying) – Hot water dipping
Slaughtering	– Innovative sanitation techniques	– Electrolyzed water – Application of biosurfactants
Processing		
Food production	– Innovative food pasteurization and preservation techniques	– Non-thermal technologies (e.g., high pressure processing (HPP), pulsed electric fields (PEF), etc.)
	– Automation of the process	– Mobile app automation – Robotics
Storage/Transportation		
Transportation	– Improvement of cold chain	– Emerging freezing technologies (e.g., high pressure, ultrasound freezing, magnetic resonance freezing and microwave freezing) – Internet of Things (IoT) in the cold chain
Storage	– Improvement of refrigeration systems – Modernization of milking equipment	– Superchilling
Storing Practices	– Proper handling	– Information technologies
Packaging/ Wholesale/Retail		
Packaging	– Smart packaging and utilization of bio-based materials	– Intelligent and active packaging – Utilization of bio-based materials
Whole supply chain		
Agricultural production, processing and storage	– Measuring food loss in the supply chain	– Value stream mapping
Agricultural production, processing and transportation	– Optimizing manufacturing and traceability across the supply chain – Monitoring of human errors and breakdown of the cold chain	– Industry 4.0 for supply chain management

In-field storage of millet, Burkina Faso
(Photo: WIPO / Oksen)

Technology solutions for agricultural production

ICT in agriculture

ICT in agriculture can help minimize food loss by reducing risk, increasing productivity, improving planning, and warning of extreme weather conditions, water stress, locust infestations, etc. Such tools can make a significant difference in particular for smallholders in developing countries. Big data (the collection and analysis of vast amounts of data from a multitude of sources) is increasingly used by international organizations and governments around the world to support accurate assessments and decision-making. During the 2020 large locust infestation in the Horn of Africa, which threatened to affect the food security of five million people (WEF 2020), several advanced ICT-based tools were used to combat the insects. FAO developed a suite of ICT-based swarm monitoring tools including a smart phone application named eLocust3m where users can send geo-localized messages and warnings about current swarm locations (FAO 2020; Gilliland 2020). Data from satellites such as the European Union's Sentinel-2 constellation were used to monitor environmental conditions such as soil moisture and vegetation favorable for locust propagation as part of a warning system, and Unmanned Aerial Vehicles (UAVs), or drones, were used to monitor crop damage, the direction and spread of the swarms, and even as pesticide-spraying air vehicles (Altaweel 2020).

On a smaller scale, technology enables the collection of detailed real-time data on factors of importance for crop production, handling and storage. For example, the EnviroMonitor Instruments created by Davis Instruments, a U.S. agriculture technology company, uses a network of sensors that provide critical field data related to climate and crop production (Davis 2020), such as soil moisture probes that allow for monitoring of in-field evapotranspiration and thereby improve irrigation decision-making. Another example is Sencrop, a French agriculture technology company, which has a community of over 8,000 connected ag-weather stations that provide more than 10,000 farmers with reliable forecast measurements in real-time, straight from the field (Sencrop 2020; World Bank 2017). The World Bank published a useful e-sourcebook, ICT in Agriculture, about the practical application of ICT in smallholders agriculture (World Bank 2017).

Technology solutions for post-harvest operations

Innovative drying methods

Semi-dried foods are gaining increased attention on a global scale due to their extended shelf life and owing to the fact that they taste, smell and feel similar to fresh products. The preparation of meat products, vegetables or fruits with intermediate moisture content traditionally includes the addition of agents that lower water activity (phosphates and salts). However, these agents can alter food flavor and may be potentially harmful to consumers (Torti *et al.* 2016). As such, increasing attention is being given to alternative drying processes leading to the development of a number of innovative technologies in recent years.

Microwave is a drying technology that generates heat from the inner part of the food tissue through dipolar rotation (molecules rotating in response to an oscillating electrical field), ionic movement, and higher vapor pressure (Qiu *et al.* 2019). For example, Kelid Machinery, a Chinese industrial machine company, markets equipment which combines microwaves with drying in order to increase the energy efficiency of the process (Kelid Machinery 2020). Another technology is infrared drying, which relies on heat transfer through radiation between a hot element and a food matrix that absorbs it directly without also heating the surrounding environment (Riadh *et al.* 2015). This process is highly energy-efficient, cheap, and provides higher dehydration rates compared to other processes (Jangam 2016). It has been implemented for different products such as the drying of meat, demonstrating enhanced drying compared to the hot air process. Another advantage is that it can be easily combined with conventional drying methods (Qiu *et al.* 2019).

Osmotic dehydration, or salting, is an age-old and well-known process that partially removes free water from high-moisture products (Ciurzyńska *et al.* 2016). Prior to drying, foods are submerged into salt and/or sugar solutions which draw moisture out of the food through osmotic processes (Nevena *et al.* 2008). Osmotic dehydration can easily be combined with non-thermal technologies to increase its efficiency. For instance, a conjugation of microwaves with osmotic dehydration is able to reduce the food-drying processing time considerably (Qiu *et al.* 2019).

For example, Sairem, a French industrial equipment producer, provides numerous microwave and radio frequency dryers covering different industrial and scientific applications (Sairem 2020). Other companies such as German Kreyenborg (Kreyenborg 2020), Indian Kerone (Kerone 2020), and Swedish Ircon Drying Systems (Ircon 2020) develop similar energy-efficient dryers using infrared radiation.

On the horizon

Another emerging technology are electro-osmotic dewatering systems that apply an electric field across a liquid's flow channel, a membrane, a porous material, a microchannel, or a capillary tube. Although these systems have not been widely implemented in the food industry, electro-osmotic dewatering is a time saving and energy-efficient process that could prove to be very efficient to remove water from colloidal materials (microscopic substance suspended in another medium, usually a liquid) and solid-liquid mixtures (Tanaka *et al.* 2014).

Sustainable sanitation

Cleaning and sanitizing procedures in food processing are extremely important for food safety. They are mostly performed with different decontamination techniques that aim to eliminate hazardous microorganisms without affecting the quality of the final product. However, common drawbacks, such as low efficacy, high cost, and risk of residues that cause adverse effects on food quality (Stoica 2018), have led specialists to seek alternative strategies to control pathogenic bacteria and for safe and environmentally benign sanitizers (Sharma *et al.* 2018).

Electrolyzed water is a disinfectant produced by the electrolysis of tap water in the presence of dissolved sodium chloride. It exhibits fast (5–20 seconds) disinfection effects on various microorganisms commonly found on food processing surfaces (Ding *et al.* 2015; Hricova *et al.* 2008), and on pathogens attached to poultry (Park *et al.* 2002). It is cheaper and safer to apply in comparison to conventional cleaning systems, providing an easily applicable and effective sanitation of food processing equipment. Electrolyzed water is highly versatile as it has different uses depending on its pH. At extreme pH values (strongly acidic or alkaline) it can be used for sterilization and cleaning of industrial devices, and in the neutral values range it is useful as drinking water and as an ingredient in cosmetic products (Rahman *et al.* 2016).

Electrolyzed water machines are marketed by several companies. A typical example is the electrolysis systems of EcoloxTech, which generate anolyte (neutral-to-acidic electrolyzed water based on free chlorine) for disinfection purposes (EcoloxTech 2020).

Microbial biosurfactants

Research, innovation and commercialization efforts for the utilization of biosurfactants (biologically derived compounds that lower surface tension) in the food industry have dramatically increased in recent years. Biosurfactants are amphiphilic chemicals (simultaneous water and fat loving, like soap and detergents) generated by microorganisms. They have proven to be very effective against microbial deterioration and particularly against biofilm development on surfaces, and as such can help prolong the freshness of food products (Santos *et al.* 2016). NatSurFact and AGAE Technologies are two companies producing rhamnolipids, which are biosurfactants made up of fats and sugars. Other biosurfactants, such as lipopeptides (bacteria-produced molecules with numerous anti-fungal and anti-bacterial applications), are manufactured by Lipofabrik, Sigma Aldrich, and KANEKA. The global biosurfactant market is expected to grow significantly in the years to come (Markets Insider 2017).

Water electrolysis system
(Photo: EcoloxTech)

Technology solutions for processing

Non-thermal technologies

It is important to maintain food quality and ensure safety during processing. While traditional heat treatments (e.g., boiling, pasteurization, drying etc.) are convenient and efficient in microbial inactivation, they have a number of disadvantages, including changing the taste, flavor, color, aroma and texture of food. They also have high energy demands and risk diminishing nutritional value, leading to food loss.

Non-thermal technologies offer alternatives, eliminating some of the above-listed drawbacks. These technologies are able to accelerate heat and mass transfer, shorten processing time, control the progress of Maillard reactions (the chemical reaction producing distinctive flavor during browning of food e.g., frying), extend shelf life, and improve the overall quality of food products. These technologies also reduce energy and water consumption, thereby reducing production costs. Among them, ultrasound, pulsed electric fields (PEF), and high pressure processing (HPP) are the most commercialized technologies.

Ultrasound can be used as a non-chemically based food preservation technology. Ultrasonic waves at frequencies of 20–600 kHz have cavitation effects (rapid formation of collapse of air bubbles in fluids) which have the effect of inactivating microorganisms and enzymes. This technology is conducted at room temperature and has a minimum degradation effect on food quality (Qiu *et al.* 2019). Hielscher Ultrasound Technology is an example of a company providing ultrasound food processing solutions.

ELEA, a German manufacturing company, provides two pulsed electric fields systems for the industry that can treat a broad range of food products for different purposes, such as low heat pasteurization, enzyme control, and extraction of aroma and valuable compounds. This technology involves the application of electric pulses of very short duration with 50-1000 kJ/kg energy input and high electric field strengths. It can inactivate pathogenic microorganisms, such as Salmonella, E. coli, and Listeria monocytogenes, by inducing critical electrical potential across the cell membranes. Its advantage is the minimal impact on foods' nutritional value and taste (Alexandre *et al.* 2019). Pulsemaster, a Dutch-German manufacturing company, offers similar pulsed electric fields systems.

High pressure processing is based on the application of high pressure (ranging from 100 to 1,000 Megapascal) on liquid or solid foods for varying time periods (from milliseconds to 20 minutes) (Alexandre *et al.* 2019; Balasubramaniam *et al.* 2015). For example, the company Hiperbaric designs industrial HPP systems used in the food industry as a "cold" pasteurization process targeting microbial inactivation of yeasts, molds, viruses, pathogenic bacteria, and spores. Similar HPP systems are offered by JBT Avure HPP and Kobelco.

High pressure processing unit
(Photo: Hiperbaric)

Technology solutions for storage and transportation

Alternative refrigeration approaches

Innovative freezing

Freezing is the most effective approach to extend the shelf life of foods and avoid food loss during transportation and storage. During industrial freezing, the storage temperature is typically lowered to below –18°C.

The development of innovative non-thermal technologies, such as freezing assisted by ultrasound, high pressure, magnetic resonance, or microwave, are often used to make the freezing process more energy efficient (Rahman and Velez-Ruiz 2007; Tavman *et al.* 2019). Swiss manufacturer M. Wohlwend is an example of a company providing solutions.

Superchilling

By maintaining the temperature of food between –1.50°C to –1.0°C, a state in between freezing and chilling is achieved in which around half of the water content in the food is frozen. This avoids the formation of large ice crystals in the food product which deteriorates the quality compared to fresh products. As a temperature slightly below this threshold results in a slow freezing process which causes the formation of large ice crystals, it is critical that the temperature is maintained in the narrow range. Superchilling slows bacteria action and hence increases shelf life, especially for fish and meat, with little effect on the quality of the food. For white fish, storage time can be increased to 15 days or more. King Son Instrument Tech. Co. provides superchilling devices with a sophisticated controller to keep constant temperature and humidity at multiple points. SKAGINN 3X offers similar solutions.

Supercooling

Another way of storing food products at low temperatures without the formation of ice crystals is supercooling. This process lowers the temperature of a liquid or gas below its freezing point, but without freezing it. Various techniques are used to achieve supercooling, including the application of electric or magnetic fields that vibrate the food molecules and prevent freezing. Examples of commercial applications can be found in Jun Innovations and Mars company, a Japanese manufacturer.

Technology innovations in packaging

Food packaging has four main elements: containment of food, protection from the environment, consumer convenience, and consumer communication. The materials used in packaging should be able to physically protect food, prevent contamination from microbes, and generally act as a barrier to alterations (Martins *et al.* 2019). Today, around 50 percent of food packaging is made with plastics, due to their low price, strength, flexibility, and effective protection from humidity and air. However, increasing awareness of the negative environmental effects of plastic production, use and waste has driven the food industry towards more sustainable options such as bio-based and/or biodegradable polymers. This approach aligns well with the aim of reducing food loss as these materials can also be generated from food by-products (Siracusa and Rosa 2018).

For example, Biopac UK and Carapac provide biodegradable materials that can be used to develop “active packaging.” Active packaging uses antioxidant and antimicrobial compounds that are released over time in packaged foods in order to increase their shelf life (Martins *et al.* 2019). Multisorb produces oxygen absorbers which can be added to the food packaging to prolong freshness.

Application based food product tracing
(Photo: Tuku)

Another approach is using so-called intelligent packaging systems where labels act as an interactive Internet of Things (IoT) gateway with consumers, informing them about the qualities and characteristics of the packaged products. This technology is not directly targeting the extension of the shelf life of foods like active packaging, but can help consumers make conscious choices such as favoring brands which minimize food loss (Martins *et al.* 2019). An example of such solutions is Tuku.

WITT-Gasetechnik, a German manufacturing company, provides modified atmosphere packaging solutions. This type of packaging is based on the modification of the atmosphere surrounding the product in vapor-barrier materials. The modification consists of replacing oxygen in the headspace of the package with inert gases such as nitrogen or carbon dioxide (Rosa 2019). Modified atmosphere packaging is often used to extend the shelf life of vulnerable foods like poultry, fish, meat and dairy products.

as humidity and temperature can be monitored using RFID sensors attached to crates and products as well as by using GPS tracking in shipping containers. By enabling IoT tools, recorded data can be transmitted in real-time to stakeholders and drivers, issuing notifications when environmental and other conditions become compromised, for example. Companies like AVSystem and Leverege develop IoT-enabled tools which may help achieve some of these goals in the supply chain. New Cosmos Electric provides odor-sensor devices which can detect indicator smells from deteriorated foods.

Technology solutions for the whole supply chain

Industry 4.0

The term Industry 4.0 is used to describe recent technological advances that have the potential to dramatically alter production systems and more. Technologies such as artificial intelligence (AI), big data collection and analyses, IoT, cloud computing, autonomous robots, and sensory technologies have potentially large implications for the food industry and can contribute to improve food safety, optimize the supply chain, and reduce food loss. Increased automation and availability of data can help reduce costs, monitor compliance with standards, and increase resource efficiency.

QR codes and Radio Frequency Identification (RFID) labels can be attached to food containers and through fast, and in some cases automated reading of the labels, food products can be traced and monitored all the way from farm to retailing. The trace and monitoring data can be collected in databases through which retailers and consumers can be informed about the product's condition and the supply chain (Hasnan *et al.* 2018). Examples of commercial solutions applying such technologies are Avery Dennison and Clearmark Solutions.

Many sources of data can be combined in cloud-based enterprise resource planning (ERP) systems which may help optimize the supply chain by providing better overview, management, and planning tools. An example of such systems is the Oracle Netsuite for the food and beverage industry. Other software-based systems use AI to perform an analysis of big data for patterns, outcomes, etc., in order to provide insights to all parties of the supply chain and ultimately reduce food loss. Analytics software relies on a large variety of data sources for performing complex analysis. This includes environmental data such as results of soil samples, rain and temperature which can help predict the quality, size and timing of the harvest, and traffic and road conditions that can affect how quickly crops can get to the market. For example, Ignite provides dedicated software for handling big data in the supply chain.

Disruptions to the cold chain can occur for a variety of reasons, including human error, mechanical problems, unexpected delays in transportation etc. Cargo-affecting variables such

From the WIPO GREEN database of solutions and technologies

The WIPO GREEN platform hosts a database of innovative green technologies and needs. Upload of needs and technologies to the database is free and open to the public, and helps inventors and solution seekers to connect. The following are a few technologies of relevance from the database.

Toshiba Corporation offers an electrode unit capable of performing efficient electrolysis processes such as the generation of hypochlorous acid water as a disinfection agent. This unit comprises an electrode substrate with several through holes that are open at the surface of the electrode's surface (Toshiba 2019).

The Green Technology Bank integrates green materials with flexible design and manufacturing solutions according to specific packaging requirements of various light industries, agriculture, and related production services (Green Technology Bank 2018).

Michigan State University has developed a direct, on-site detection method of bacteria for milk, juice and other products. The technology is based on a wireless reader consisting of an RFID-compatible sensor and a disposable smart vial generated by a 3D-printer. This device detects on-time contamination without the need for long laboratory analysis. The detection of coated bacteria is based on their interaction with a biosensor strip (dextrin-coated gold nanoparticles).

The United States Department of Agriculture (USDA) Agricultural Research Service (ARS) Plains Area has developed an integrated set of sensors and software bearing devices that are capable of measuring surfaces remotely. This system can be used in drip-irrigated fields to aid with monitoring plant abiotic (chemical, drought, etc.) and biotic stresses (insect infestation, diseases, etc.). Applications include crop yield forecasting, irrigation scheduling, and detection of crop nutrient deficiencies and diseases.

Conclusion

Innovative technologies to tackle food loss in the supply chain is a vibrant field with large potential. Its scope ranges from exploiting physical and chemical properties in new ways that prolong product freshness, to smart packaging and use of advanced sensors, big data and AI to optimize supply chains and minimize food loss. At every critical loss point there are technologies available which offer improvement, many of which also increase energy efficiency. As food loss is closely related to food security, technologically based solutions and improvements have the potential to play an important role in achieving the SDGs.

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The WIPO Global Challenges Division is responsible for addressing innovation and IP at the nexus of interconnected global issues, with a particular focus on global health, climate change and food security. The Division's activities, including the two multi-stakeholder platforms it administers and trilateral cooperation with the World Health Organization and World Trade Organization, aim to harness the power of innovative partnerships to generate practical solutions for the benefit of all – especially developing countries.

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