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INTERNET OF THINGS APPLICATION IN AN AGRICULTURAL FOOD SUPPLY CHAIN TO REDUCE FOOD LOSS AND WASTE

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ABSTRACT

INTERNET OF THINGS APPLICATION IN AN AGRICULTURAL FOOD SUPPLY CHAIN TO REDUCE FOOD LOSS AND WASTE

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In this study, in order to prevent or reduce food loss and waste throughout the food supply chain, it has been examined to what extent corporate companies that produce and export perishable agricultural products benefit from the Internet of Things technology in their operational activities and whether they will include such applications in their future investment plans. The effect of the Internet of Things technology in reducing food waste and loss along the supply chain was examined by scanning the literature and conducting a 20-question survey including Yes/No, Open-Ended, and 5-point Likert Scale question types. It is an undeniable fact that companies attach importance to the idea of “less food loss and waste” with their sensitive attitudes towards the use of natural resources, their investments to reduce the damage they cause to the environment throughout the supply chain, and their sustainable future goals. Although companies benefit from some Internet of Things applications to ensure food safety in certain processes of the supply chain, reduce or prevent food loss and waste in economic and social terms, to invest in an integrated Internet of Things technology that covers all processes and to make loss prevention or reduction processes more efficient, awareness studies should be carried out to companies and investment incentives should be provided by the state.

keywords: internet of things (IoT), food loss and waste (FLW), agri-food supply chain

ÖZ

GIDA KAYIP VE ATIKLARINI AZALTMAK İÇİN TARIMSAL GIDA TEDARİK ZİNCİRİNDE NESNELERİN İNTERNETİ UYGULAMASI

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Ocak 2022

Bu çalışmada, gıda tedarik zinciri boyunca gıda kayıp ve atıklarını önlemek veya azaltmak için, bozulabilir tarım ürünleri üreten ve ihraç eden kurumsal firmaların operasyonel faaliyetlerinde Nesnelerin İnterneti teknolojisinden ne ölçüde yararlandığı ve gelecek yatırım planlarında bu tür uygulamalara yer verip vermeyeceği incelenmiştir. Nesnelerin İnterneti uygulamalarının tedarik zinciri boyunca gıda kayıp ve atıklarını azaltmadaki etkisi literatür taranarak ve Evet/Hayır, Açık Uçlu ve 5 puanlık Likert Ölçekli soru türlerinin yer aldığı 20 soruluk anket çalışması yapılarak incelenmiştir. Şirketlerin doğal kaynak kullanımına karşı duyarlı tutumları, tedarik zinciri boyunca çevreye verdikleri zararı azaltmaya yönelik yatırımları ve sürdürülebilir gelecek hedefleri ile "daha az gıda kayıp ve atığı" düşüncesine önem verdikleri yadsınamaz bir gerçektir. Şirketler, tedarik zincirinin belli süreçlerinde gıda güvenliğini sağlamak, ekonomik ve sosyal açıdan gıda kayıp ve atıklarını azaltmak veya önlemek için belirli Nesnelerin İnterneti uygulamalarından yararlanmalarına rağmen tüm süreçleri kapsayan bütünleşmiş bir Nesnelerin İnterneti teknolojisine yatırım yapmak ve gıda kaybı önleme veya azaltma süreçlerini daha verimli hale getirmek için şirketlere farkındalık çalışmaları yapılmalı ve devlet tarafından yatırım teşvikleri sağlanmalıdır.

Anahtar Kelimeler: nesnelerin interneti (IoT), gıda kayıp ve atıkları, tarımsal gıda tedarik zinciri

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Asya Gizem SAYAR

İzmir, 2022

TEXT OF OATH

I declare and honestly confirm that my study, titled “INTERNET OF THINGS APPLICATION IN AN AGRICULTURAL FOOD SUPPLY CHAIN TO REDUCE FOOD LOSS AND WASTE” and presented as a Master’s Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Asya Gizem SAYAR
25/01/2022

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

FLW: Food Loss and Waste

IOT: Internet of Things

Auto-ID: Automatic Identification

RFID: Radio-Frequency Identification

EPC: Electronic Product Code

RFI: Radio Frequency Interface

WSNs: Wireless Sensor Networks

NFC: Near-field Communication

UWB: Ultra-Wideband

ICT: Information and Communication Technologies

M2M: Machine-to-Machine

CPS: Cyber-Physical System

ML: Machine Learning

DM: Data Mining

VoIP: Voice Over Internet Protocol

FAO: Food and Agriculture Organization

FSC: Food Supply Chain

GHG: Greenhouse Gases

GWP: Global Warming Potential

OECD: Organisation for Economic Co-operation and Development

ERS: Economic Research Services

FUSIONS: Food Use for Social Innovation by Optimising Waste Prevention Strategies

EPA: Environmental Protection Agency

USDA: United States Department of Agriculture

EU: European Union

PHL: Post-Harvest Loss

SCM: Supply Chain Management

GDP: Gross Domestic Product

AI: Artificial Intelligence

IPCC: Intergovernmental Panel on Climate Change

WRAP: Waste & Resources Action Programme

SDGs: Sustainable Development Goals

PWC: Pricewaterhouse Coopers

SSC: Smart Supply Chain

EDI: Electronic Data Interchange

IR: Infrared

NMR: Nuclear Magnetic Resonance

TTI: Time-Temperature Indicators

CTI: Critical Temperature Indicators

CTTI: Critical Temperature/Time Integrators

HPP: High-Pressure Processing

MMR: Mixed Method Research

CHAPTER 1
INTRODUCTION

Food loss and waste, or in short FLW in agricultural food supply chains occur at an undeniable amount. Rapid global population growth, climate change, depletion of limited resources, and loss and waste in the agri-food system threaten the ability of current and future generations to secure food and nutrition. With the global COVID-19 pandemic, it was once again understood how important the global and national food supply is. This research aims to reveal how widely the “Internet of Things” technology is used by companies producing and exporting agricultural food products in Turkey to prevent or reduce FLW during the distribution phase of the agricultural supply chain, where food waste is concentrated. Thus, considering the contributions of the Internet of Things application in the agri-food supply chain; In order to better analyze how widely the companies producing and exporting agricultural food products in Turkey use the “Internet of Things” technology, a 20-question survey was conducted with a mixed-method including quantitative and qualitative methods. In order to understand the participants’ perspectives on the subject in a wider context, a semi-structured interview technique was preferred in the qualitative part of the questionnaire; On the other hand, in the quantitative part of the questionnaire, 5-point Likert Scale Questions containing tables and pie charts are given to the participants to contribute to the analysis in the numerical context. The appendix contains detailed information about the full version of the survey. As a result of the literature review and research, the perspectives of corporate companies producing perishable agri-food in Turkey, how much and at which supply chain stages they benefit from the Internet of Things applications, what are the motivations or barriers in investing in IoT technologies, whether future companies have Internet of Things applications in their future investment plans, and the positive contribution of the state contribution to the Internet of Things usage rate was measured.

1.1. The Scope of Internet of Things

Geographical borders do not matter in a globalizing world. The most important reason for this is the rapid development of mass media. The use of mass media instruments, which is an important part of our lives today, has removed the importance of existing country borders. Mobil devices and services that offer connectivity from anywhere are getting rise continuously year after year owing to the major development in the area of electronics and the infrastructure of wireless communication systems. Nowadays, the use of mobile devices is not only limited to connecting people to the internet but also has also spread, getting the possibility to connect the physical world with the virtual world. Thanks to the digital connection opportunity between these two different worlds, important developments have been achieved in terms of human history.

Internet, which is the most extraordinary invention of technological developments in this period, which is called “the information age” today, has brought a different dimension to the concept of globalization. The internet is an effective universal communication instrument that allows people to instantly access desired data by providing opportunities and benefits to developed and developing regions regardless of geography, culture, language, and time zone (Rose et al., 2015). One of the most important digital tools of the widespread use of the internet is the computer. However, with the prevalent use of smartphones, internet access has taken its place in our daily lives. At present, up to 3.9 billion people have access to the internet which means more than half of the entire population is from 180 different countries. The internet connection and effective data analytics not only affect the world population individually, but also becoming a fundamental part of many establishments, industrial and, consumer products in order to ensure access to information owing to being interconnected with everyday objects such as vehicles, final products, durable goods, industrial and components, sensors, and others. The internet’s drastic transformation into a network of interconnected things that, while gathering data from the environment and interacting with the actual world, also employ existing internet principles to ensure data transit and analytics, applications, and communications (Gubbi et al., 2013).

All developments in technology in the globalizing world create an excellent environment for increasing the impact of the Internet of Things (hereinafter mentioned to IoT), which leads to physical things to communicate over the networks offering a revolutionary, completely connected intelligent world with intertwined relationships between objects and their surroundings. The IoT is a reform of technology on the basis of computing and communication, which enables the sight of communication whenever necessary through any path/network and service (Luthra et al., 2018; Li et al., 2015; Porkodi & Bhuvaneswari, 2014). The IoT enables every technological object, anything in the world, to be able to connect to each other by providing a unique identity to each one through internet access, make decisions on its own, and provide services to any person at any time with the help of a network from anywhere (Zeinab & Elmustafa, 2017). The rate of IoT adoption is almost five times higher than that of power and telephony (Balas et al., 2020). Even, more than 120 new IoT devices connect to the internet every second around the world (Davis et al., 2020). These data show that the use of IoT will increase day by day. Thanks to its self-configuring capabilities, IoT integration is considered as part of the internet of the Future (de Saint-Exupery, 2009).

Today, the IoT is still an incomplete technology in its development and progress. The most common IoT implementations can be listed as smart cities, smart cars, smart homes, and smart meters (Jagtap & Rahimifard, 2019). The IoT, which can also be thought of as a dynamic international network, provides interaction between things-to-things, human-to-thing, and human-to-human (Aggarwal & Das, 2012; Madakam et al., 2015). The main goal of the IoT is to create an efficient system and a better world for people by using a common infrastructure to unite and control everything from the different fields in our world (Ben-Daya et al., 2019). All these developments in IoT technologies have a strong impact on the business management field and change business life to a greater extend.

1.1.1. The History of Internet of Things and Its Relations with Radio-Frequency Identification System

Automatic Identification (Auto-ID) technology that can be used to make objects smart is one of the fundamental technologies in IoT (Zhong et al., 2017). The idea of the existence of smart objects or smart things started circulating around Carnegie Mellon University in the early ‘80s. The first soft-drink machine connected to the internet, the machine could tell its guide how many drinks were left and whether they were cold enough (Farooq et al., 2015). Furthermore, automation of everyday objects was first attempted by several industries in the ‘90s in an attempt to transmit information from one data point to another data point in small packets. In 1991, Mark Weiser groundbreakingly discovered the computing capacity of the IoT, which is used in every field today (Farooq, 2015; Weiser & Brown, 1997). Bill Joy first coined the concept of device-to-device communication at the World Economic Forum in 1999. (Tewari & Gupta, 2020). British technology pioneer Kevin Ashton, also head of the Massachusetts Institute of Technology’s Auto-ID Center, first used the term “Internet of Things” in 1999 to describe a structure in which things in the real world would be interconnected via sensors. The word was coined by Ashton to describe the power of connecting Radio-Frequency Identification systems or RFID in short, tags are also known as transponders used in corporate supply chains to the internet with regards to count and track goods (McFarlane et al., 2003). Lately, Bruce Sterling introduced the notion of combining IoT applications with smart objects (Madakam, 2015). In fact, in less than 30 years, we can see how the IoT technology, which was created using the RFID basis, has evolved and become widespread in our daily life in a short time, with the contributions of the valuable opinions of scientists.

RFID is seen as one of the main providers of the IoT (Tan & Wang, 2010). With the application of RFID, initial technical substantiation of IoT has been accomplished, such as identifying and tracking devices and storing device data (Hong et al., 2014). Moreover, RFID technology was not a new idea at the time, which was used even in the Second World War, Robert Alexander Watson-Watt, a Scottish physicist, was the first to discover it in 1935. The Identification Friend or Foe transponder, known as a radar-based identification system improved in the United Kingdom, was used by allies to determine whether the plane was a friend or an enemy (Jia et al., 2012; Roberts, 2006). Towards the ‘90s, RFID systems started to take modern forms like we know today. In the early ‘90s, in Oklahoma, United States, the implementation of RFID as an electronic toll system where vehicles can pass through toll collection points at highway speeds attracted great attention by European countries (Roberts, 2006; Landt, 2005). With the development of personal computers, RFID applications started to increase rapidly because computers provided appropriate and cost-effective collecting and information processing from RFID systems (Landt, 2005). Nowadays, in more than a hundred countries worldwide, billions of people use RFID systems without knowing, ranging from vehicle parking access control, supply chain and inventory tracking, retail stock management, postal tracking, tracking library books, theft control, motorway tolls, airline baggage management, etc. (Roberts, 2006).

Overall, the RFID system has two main components in common: tags (also known as transmitters or responders) and readers (also known as transmitters or receivers). The primary function of these tags which is composed of a small chip is to collect real-time data via radio waves and process and a coiled antenna is used to use for transmitting and receiving electromagnetic waves carrying information from the reader to tag. Today, RFID tags are things that can be created as adhesive tags and are reduced to the size of rice grains that can be attached to any object (Rieback et al., 2006; Landt, 2005). Object identification acts as a bridge providing a seamless connection between the physical and virtual world (Vogt, 2002). The Electronic Product Code (EPC) is a matchless code that changes from label to label. A unique identification number of the object known as an EPC or product being tracked is stored in the chip embedded in the tag. This number is part of the information. Even the general application of the EPC worldwide network is based on the IoT system integration (Tu, 2018; Yan & Huang, 2009). When a tag passes, this information is read by an RFID reader, which consists of a decoder to decode the information of tag (Valdramidis & Koutsoumaniad, 2016), and the reader detects and records the information encoded in the tag, allowing it to track the actual movement of the object containing the tag in real-time and the digital identity of the object and other relevant information transfers to a computer system (Zhu et al., 2012). The Radio Frequency Interface (RFI) module and control unit also make up the reader, also known as the transceiver. The main purpose of the readers is to first activate the tags and then to communicate data between the application program and the tags, configure the communication sequence with the tag (Jia et al., 2012). Moreover, RFID scanners can read multiple tags at the same time and allow both single item and batch scanning (Alam et al., 2021). The RFID tag can survive harsh environments and cannot get dirty or damaged easily (Tu, 2018). Although RFID tags have a limited reading range, they do not need a clear line of sight or physical connection to communicate with scanners (Alam et al., 2021). One of the advantages of RFID readers is allow batch scanning of products while receiving information from an RFID tag via radio waves without line-of-sight operation (Tu, 2018).

Relying on energy demands, RFID tags fall into two broad categories, namely active tags and passive tags. Passive ones that do not have a battery and need an external power to provide signal transmission, and semi-active ones, which are battery-powered passive tags that only use batteries to power the microchip circuit (Valdramidis & Koutsoumaniad, 2016), use active tags have an internal power source, which is a battery, and are powered by the radio frequency wave emitted by the readers to communicate (Rieback et al., 2006). Active tags are those that have their own power source, allow real-time traceability as they can send information continuously (Alam et al., 2021). The active tag enables communication over miles, thus much more expensive and larger than passive ones and commonly used for identifying the national origin of the aircraft.

Also, the focus is on developing low-cost chipless RFID tags today (Liegeard & Manning, 2020; Wittkopf et al., 2018). Chipless RFID offers cost savings compared to chip ones and can be identified even if the tag is blocked and therefore valuable in future smart packaging applications (Wittkopf et al., 2018). Having an unlimited life and being cheaper and smaller enough to fit an adhesive application label makes passive tags more popular (Kaur et al., 2011). Furthermore, these tags can be read in challenging weather conditions (fog, ice, snow, etc.) or visually challenging conditions such as paint and dirt, which is the main benefit of the RFID system (Roberts, 2006). It is inevitable that the use of these chips in industrial areas will become widespread, upon making these chips more resistant to challenging conditions and minimizing their size. With this widespread use of chips, businesses will improve their operations and make them more efficient.

The RFID system, which works as an automatic data collection terminal, provides information input to the IoT by reading and processing the tags' metadata (Yan & Huang, 2009). The rapid increase in passive RFID tags led to the emergence of various developments like IoT, which is the most popular concept nowadays (Welbourne et al., 2009). The critical difference between RFID and IoT; in the RFID technology, there is a line of sight between the reader and the tag for reading said tags and often does not work without human intervention (Vogt, 2002). This difference in the use of IoT technology, together with the increase in the number of digital products communicating with each other, contributes to the widespread use of IoT and also helps to increase the diversity of application areas. After the historical development of IoT, it will be useful to examine tools and technologies utilized by IoT studies.

1.1.2. Sensors and Its Relations with Smart Things

While using tags in RFID technology, sensors are at the forefront, which plays a crucial role in connecting the physical world and the information world in IoT technology. Sensors monitor their surroundings and collect data from them and generate contextual awareness (Tan & Wang, 2010). These sensors are embedded in objects. Thus, "things" that become smart with sensors are called smart objects or smart things, and they can process information, self-configure, decision-independent. Smart objects are the first step of an evolutionary process and have been triggered by the emergence of IoT (Atzori et al., 2014).

IoT is a network of uniquely addressable connected and smart devices that can communicate in real-time. Moreover, all human sensory abilities may perform more uncertainly than sensors. In this regard, the presence of sensors enables us to transfer the maintenance of environments to technology (Nolin & Olson, 2016). Actuators, sensors, and embedded systems that interact with the wireless connection, creating up IoT devices become less expensive and smaller, which promotes their use widespread in all areas. Through the rising network capacity of wireless sensor networks (WSNs) nodes IoT implementations, over the next decade, more than 50 billion smart devices in other words an average of 6.58 connected devices per person, will be able to connect to internet services and to each other. IoT is quickly being one of the most key technologies in everyday life allowing gadgets to communicate with one another via the interconnection of technological solutions such as RFID, WSNs, Bluetooth, and near-field communication (NFC), as well as data analytics, cloud computing, and internet protocols all of which are commonly employed to launch successful IoT-based product and services. Even though IoT network connectivity is provided by using technologies and networks developed for different purposes such as Wi-Fi, GSM, LTE, Bluetooth, there are such technologies developed for specific usage for IoT like nWave, RPMA, Dash 7 Alliance Protocol 1.0, LoRaWAN, IEEE P802.11ah (Quinnel, 2015; Borgia, 2014). The low energy consumption of these networks, which are specifically built for IoT applications, is their most crucial attribute. New technologies are expected to function for many years, if not decades, on a single battery. This is because, unlike older technologies, where data transmission consumes the most energy, contemporary gadgets consume far less energy in this area, with the sensor being the device's most energy-consuming component (Stočes et al., 2016).

1.2. Structure of Internet of Things Layers

IoT lacks a uniform framework and is still evolving and attempting to find its final form. IoT, which is in constant change and development, has several temporary domains consisting of three, four, or five layers. Nevertheless, these structures have some similar features in common. Originally, the most popular IoT structure consists of three layers, namely, the perception layer, the network layer, and the application layer (Tzounis et al., 2017; Zeng et al., 2017).

1.2.1. The Perception Layer

The purpose of the first layer, which refers to the perception layer (also known as the sensing layer) is to uniquely identify objects in the IoT ecosystem that can be realized by gathering information about each object and transforming this information into digital signs. It also sends and receives other data from the media and upper layers for processing. The sensing layer can be divided into two layers as data acquisition and collaboration layers according to the functions of the units. Weather conditions, humidity, pressure, intensity, and multimedia data from the real world are identified utilizing RFID tags, Ultra-Wideband (UWB), NFC, Wi-Fi, and cameras in the data acquisition layer. Middleware technology, coordination treatment technology, Ad-hoc network and, WSNs, are used in the collaboration layer to concentrate on innovations used in the short-distance transmission of data, context awareness, and huge information analysis (Witjaksono et al., 2018). The perception layer can be 2-D barcode labels and readers, sensors, terminals, RFID tags, cameras, GPS, etc. (Wu et al., 2009). To be considered IoT detection devices, they must communicate directly or indirectly with the internet. A direct connection to an Arduino or Raspberry Pi via Ethernet or Wi-Fi is considered a direct connection, whereas an indirect connection to Zigbee or Bluetooth devices via a Zigbee gateway or mobile phone is considered an indirect connection (Jagtap & Rahimifard, 2019). The IoT mediatizes a number of technologies that already exist, namely RFID and WSNs, end-user applications, middleware systems, Cloud Computing, and RFID enable microchips to transmit the information to a reader through wireless communication. Even though many objects cannot be detected directly in real life, in this context, they have the opportunity to place a microchip that can detect moisture, temperature, or speed in their bodies. Embedded intelligence technology and nanotechnology are the major technologies in the perception layer in this context that allows the chips to be reduced enough to be placed in any object (Wu et al., 2009).

1.2.2. The Network Layer

This layer is known as the core of the IoT (also known as the data transfer layer), transmitting the information gathered by the perception layer such as software and hardware. The network layer consists of networks of mobile phones, fixed phones, broadcasting, and closed IP data for each carrier (Madakam et al., 2015). At the perception layer, we encounter the technology RFID, WSNs and NFC. WSNs use interconnected smart sensors for the purpose of sense and monitoring. It has also been used for monitoring environmental, industrial, healthcare, traffic, and so on (Li et al., 2012; He & Da, 2012). The second layer of IoT wireless send nodes communicate with neighboring nodes or a gateway that interacts with physical objects or their surroundings, establishing networks where data is often routed to a remote infrastructure for storage, allowing further analysis and the resulting valuable information being processed and disseminated (Gubbi et al., 2013). Although there is a variety of commercial gateways/routers that are compatible with an IoT system today, the only issue is providing a constant power source to the gateways (Holmström et al., 2019).

1.2.3. The Application Layer

The application layer is known as a service layer (also known as the data storage and manipulation layer) which task is based on data processing in the process layer and develops the diverse applications of IoT. The application layer provides all kinds of applications for each industrial area (Wu et al., 2009). In this regard, this layer is very effective in the large-scale development of the IoT network (Farooq et al., 2015).

1.3. Characteristics of Industry 4.0 in the Context of Internet of Things

A new industrial revolution is currently taking place as a result of the advancement of Information and Communication Technologies (ICT). This development, which began with the introduction of IoT into the production environment and is referred to as the 4th industrial revolution according to the smart enterprise model, was first introduced in 2011 at the Hannover fair in Germany under the motto computerization of industrial production (Veza et al., 2015; Okano, 2017). While the German government digitized manufacturing industries in its 4.0 program, the Smart Manufacturing Leadership Coalition program was promoted in the United States, and other large production companies as follows China, Japan, and Korea set the domestic action plan for SMART supply chain programs (Chaopaisarn & Woschank, 2019). The idea behind this initiative is; linking production machines, processed products, semi-products, and all people to each other via computer, which is that all systems can be integrated into an intelligently distributed heterogeneous asset network along a chain (Poor & Basl, 2019). In this regard, Industry 4.0 ensures that all participants in the company's value chain, from suppliers to customers, are integrated with the integration of business and production processes at the same time (Rojko, 2017). IoT-enabled manufacturing provides real-time data collection and sharing opportunities between various production sources, namely machines, people, materials, and jobs (Bi et al., 2014). Industry development is a multi-step process involving machines and humans that is both sophisticated and agile (Roblek et al., 2016). As a result of this integration, the smart manufacturing concept has emerged. Smart manufacturing aims to optimize production and product processes by taking full advantage of advanced knowledge and production technologies (Kusiak, 1990).

1.3.1. Cyber Physical System

Industry 4.0 prepares industrial facilities with sensors, actuators and, autonomous systems, making the production smarter, adaptable and, energetic (Lu, 2017). Since the smart factory's goods are supported by sensors and microchips, these products are likewise called smart. Under the architecture of IoT, the autonomous interconnection between actuators, smart sensors, embedded processors, computers, and mobile devices with no or really limited human intervention is called Machine-to-Machine communication or, in short, M2M (Watson et al., 2020). M2M communications serve as a key enabler for the IoT to become a reality. Overall, M2M networks are divided into two categorize as capillary and cellular. The capillary network is a local network that connects M2M devices using short-range communication protocols through Wi-fi, Zigbee. While cellular network, M2M devices contain built in SIM cards and can independently communicate with the cellular network by themselves (Aijaz & Aghvami, 2015).

Cyber-Physical System or, in short CPS is an evolution of M2M developed with the emergence of a smarter and interactional mechanism based on the IoT structure (Chen et al., 2012). Thanks to the cyber systems that were a milestone in the formation of smart factories, machines took over the work of people in a monotonous and stereotyped way. But in the new global world developing without slowing down, the CPS will enable machines to exchange information autonomously, will be able to take necessary actions in real-time in response to instant conditions and independent controls using standard internet-based communication protocols (Poor & Basl, 2019; Lee et al., 2014). Through sensors, software, and electronics, basic infrastructures, CPS and IoT provide the gathering and transfer of industrial data (Li et al., 2019).

1.3.2. Cloud Computing

Nowadays, data processing often takes place in remote locations using high-performance computers; this phenomenon is called “cloud computing”. For businesses and users, Cloud Computing, which enables access to on-demand applications from anywhere, helps central data storage thanks to its virtual infrastructure. An increase in storage capacity and the ever-decreasing costs will result in the local availability of much of the information required by people or things (de Saint-Exupery, 2009). Cloud Computing promises omnipresent accessibility, dynamic resource discovery, and composability, all of which are necessary for new age IoT applications (Tiwari, 2016). With the acceleration of information technologies, the constant communication of objects, people, and services with each other via the internet generates an enormous amount of data which have to be stored, processed, and presented.

1.3.3. Big Data and Analytics

Big data is unmatched in data volume, diversity, and speed (Wu et al., 2016). While large quantities of industrial data are gathered during M2M communication, big data analytics is used to efficiently organize and easily interpret this valuable data. The correct interpretation and strategic use of data have an unprecedented impact on our world and lifestyle, benefiting both society and business organizations. In order to benefit from this collected data, companies need to create a suitable data source, create models that predict and optimize according to the results, and integrate organizational processes into transformation (Barton & Court, 2012). Utilizing the use of these technologies to integrate the generated data and make more intelligent and more calculated decisions leads organizations to make more informed decisions (Shao et al., 2021). Big data directly affects every industry branch, namely healthcare, education, production, governmental issues, retailing, etc.

1.3.4. Machine Learning

Machine Learning or in short ML algorithms, real-time data capture, analytics results, and previously successful behaviors are all used by autonomous systems while making their own decisions (Rojko, 2017). ML approaches to create an opportunity for modeling patterns and correlations in data in order to uncover linkages between situations and generate predictions based on events that have yet to occur (Iqbal et al., 2020). ML is the process of programming computers to maximize a performance measure on the basis of previous experience or data. Uses statistical theory as the main purpose of ML is to construct mathematical models by inferring from a sample (Alpaydin, 2020). ML has several applications, the most significant of which is Data Mining (DM). DM is the search for relations using a computer program that will enable us to predict the future from among large data heaps. DM can be shown as a crucial approach in advanced analytics to make sense of and interpret the connections between data (Leventhal, 2010). DM, the concept that emerges as a result of the natural evaluation of technology, should be more appropriately named “knowledge mining from data” (Han et al., 2011).

Data generated or captured by IoT, transformed into information with the help of DM to provide people with a more efficient environment. Technically, everything on IoT is about data that contains different kinds of useful information. Data based on IoT technology can be classified in two ways. The first is to use “data about objects” as reference data describing things themselves, i.e., state, location, identity, etc. The second is “data generated by objects”, data generated or captured by objects (Ali & Abu-Elkheir, 2012). While IoT devices generate helpful information to be able to generate data in some form or the other, the data analytics system processes the generated data in terms of interpretation. All these devices are needed to be supported by any application improvement structure for the IoT (Porkodi & Bhuvaneswari, 2014). As the support provided increases, an integration between all devices will be provided. The entire integration of IoT with human beings allows keeping real-time decisions in terms of communications, cooperation, and technical analytics (Ray, 2017).

1.4. Internet of Things Application Areas

Though the IoT is still a new technology, it has gained a lot of traction in recent years since it covers a wide range of application disciplines that influence a substantial portion of the world's population. IoT applications create an interface between users and devices. The application of IoT is implemented in numerous distinctive fields, from individuals to companies (Nord et al., 2019). The IoT usage rate is rapidly evolving and growing with the countless different industries, including healthcare service, workplace and home support, industrial automation, environmental management, smart city, smart home, intelligent transport, logistics, security and surveillance, disaster and response, among other fields (Ni et al., 2017; Porkodi & Bhuvaneswari, 2014; Khan et al., 2012).

One of the most common IoT applications we can easily realize in a daily life environment is "smart-home" which contributes to daily life in many ways. These modern systems provide the opportunity to interact in real-time via tablet, mobile phone, or computer while in-home or away from home as per our needs. This concept which makes up a huge market for IoT gadgets has revolutionized the way we run our daily activities at home while also allowing us to remotely control our home environments (Davis et al., 2020). A smart television, smart lighting, and heating systems, smart locks, smart security cameras, kitchen appliances, home system monitors are some of the applications that make up the concept of smart home systems. While home automation contributes to the routines of our daily lives, it helps to save money for the consumer while ensuring more efficient use of energy and natural resources.

The number of people settling in cities increases every year, which causes an increase in the pressure on infrastructure problems which are one of the disadvantages of urbanization. The emerging urbanization problem increases the importance of constructing the infrastructure in the cities in a planned and sustainable way, the correct arrangement of the existing infrastructure, and the more efficient and effective management of the living conditions of the people living in the cities. New technologies will be an important component of ensuring the ordinary processing of cities in certain problematic and challenging conditions (Nižetić et al., 2020). Many countries around the world use internet technologies, regardless of their degree of development, to ensure sustainable growth and economic development (Macke et al., 2019). “Smart Cities” can be an example of another major IoT application in our daily lives, which includes called smart security, building, infrastructure, energy, mobility, governance, education, and health. IoT applications in smart cities provide an opportunity for premature determination of various issues such as traffic congestion, power resource supply, water scarcity, security incidents, or infrastructure malfunctions (Nižetić et al., 2020). The purpose of IoT-enabled systems to create smart cities is, to create better infrastructure for urban cities, to regulate waste management, contribute to the improvement of transportation and human life (Sharma et al., 2020; Patel, 2019; Paulchamy et al., 2019). For instance, shared bicycle systems, which are being implemented in more cities globally, continue to be part of smart cities. With the help of a developed smartphone application, users can see the stations of the bicycles that they can rent for a certain fee and are monitored for security until they receive and return the bicycles (Porter & Heppelmann, 2014). With the cycling practice shared in a convenient way, the use of bicycles among the city residents becomes widespread, and the traffic is relaxed with the cars whose usage is reduced, and the carbon emission that damages nature decreases. There are many IoT applications used in transportation that integrated numerous smart vehicles with traffic management systems to ensure a safe environment (Memos et al., 2018). The smart cities industry, which was valued at $624.81 billion in 2019, is predicted to expand to $1.088.02 billion by 2025, according to the Trends and Forecast (2020-2025) Report. In addition, in accordance with Smart City Index Report 2020, Singapore, Zurich, and Oslo top the list of smartest cities (Bris & Lanvin, 2020). More and more cities continue to adopt and implement the smart city concept.

The primary aspects that can contribute to the economic and social development of emerging countries are smart homes and smart cities with IoT-related Big Data applications (Mital et al., 2018). Smart Retailing and Supply Chain Management is another common application. RFID applications have been used by the retailing industry for many years. Since the retailing sector includes various product management in supply chains, RFID applications provide such convenience and benefit. With this application, the retailer can easily track the stocks in the store, order new ones if there is a decrease in stock, or detect theft events, and even create sales diagrams and graphs for an effective strategy (Farooq et al., 2015). While the internet has become a part of human life and integrated into our daily lives, IoT applications aiming to facilitate the business world will become widespread in the future with the support of new tools and technologies.

1.5. Internet of Things and Its Relations with Business Life

IoT also called the "Internet Everything" in other words "Industrial Internet" affects both consumer and industrial sectors on a large scale. Based on its use in industrial applications, IoT is making a huge contribution to reforming the industry. The IoT blends the internet's global reach with industrial management, coordination, and control capabilities. It has affected the culture and business revolutionarily, such as electronic mails, texting, phone calls, voice over internet protocol (VoIP), social media, online shopping (Verdouw et al., 2016). In accordance with one of the most prestigious management consulting firm McKinsey Global Institute, the entire financial impact of the IoT on the global economy, which covers intelligent and embedded systems, infrastructure purpose-built IoT platforms, analytics, shipments, security, professional and connectivity services, will be more than $11 trillion by 2025. (Nord et al., 2019; Manyika et al., 2015). Developing nations stand to gain a lot from the IoT in terms of social, environmental, and economic benefits (Khanna & Kaur, 2019; Rose et al., 2015). By offering more precise and actual-time visibility into the movement of resources and products, the IoT brings a new perspective to corporate activities ranging from manufacturing lines and warehouses to retail distribution and store shelves (Lee & Lee, 2015). Smart and interconnected products are currently transforming the competition and restating the industry (Porter & Heppelmann, 2014).

With the result of increasing competition in today's business world, accurate information that can be accessed in real-time is of great importance. Easy real-time access to data and information located far from your location is possible due to the network of interconnected devices. In IoT, the fact that the devices are connected to each other in real-time contributes to the increase of efficiency while reducing errors by providing transparent and fast processes. The IoT provides monitoring and control possibilities that enable to reduce costs and increase productivity by allowing data collection and analysis, which enables the identification of potential improvement areas as well as operational models (Lee & Lee, 2015). On the other hand, the IoT focuses not only on modifying existing assets and production technology but also on developing a network that connects these assets and technologies utilizing today's ICT platform (Trappey et al., 2017). Interconnected devices are able to implement algorithms and analytics to current or past data in order to significantly develop results, benefits, and productivity. As a result, the rich flow of monitoring data from linked devices, combined with the ability to manage product operation, enables organizations to enhance product performance in a variety of ways, many of which were previously impossible (Porter & Heppelmann, 2014).

In the next part, the study will continue with agricultural FLW in FSC to determine and define the problem of FLW for further analysis of possible solutions in the context of IoT.

CHAPTER 2
AGRICULTURAL FOOD LOSS AND WASTE IN FOOD SUPPLY CHAIN

Agriculture, which provides 95 percent of the food people consume during daily life, plays a significant role in human history as it is the source of life and contributes greatly to the development of humanity by meeting the basic nutritional needs throughout ancient civilizations and will maintain this importance as long as life continues. Agriculture is an indispensable sector in the entire world owing to its contribution to many fields such as employment and national income, the supply of raw materials and capital for the other segments, direct or indirect effects on exports, meeting the nutritional needs of the country population, biodiversity and ecological balance (Doğan et al., 2015).

In the last decades, the agricultural sector has transformed over time in tackling critical challenges in the food production phase. These improvements have mainly been achieved through non-digital technologies namely animal and plant breeding, mechanization of field operations, and more environmentally friendly farming methods (Verdouw et al., 2019). Continuously developing the world economy, enhanced exchange of knowledge and technology with the effect of industrialization, liberal trading, and globalization in the 20th century contributed that people reach a fresh, safe, and healthy agri-food product anytime and anywhere. However, this phenomenon does not affect all countries and all people in the same way, at the same time. It varies according to the development level of countries or cultural differences.

2.1. Food Loss and Waste and Its Relations with Increasing World Population

World consumption per capita has increased through the development of world trade and the rising income of countries and people (Doğan et al., 2015; Halloran et al., 2014). Further to that, the world's population is expected to grow up to 9.7 billion people by 2050, which refers to current food production will require a 70% globally increase and 100% in emerging countries if current production and consumption behavior remains unchanged (Flores & Villalobos, 2020; FAO, 2019; UN, 2019; Swaminathan, 2016; Alexandratos & Bruinsma, 2012; Hodges et al., 2011; Gomiero et al., 2011). The expected increase in the world's population and not using resources efficiently creates the challenge of providing enough supply of agri-food production in order to feed the world's population in the following decades. But the pressure will increase on farmland and other limited resources to produce enough food to sustain a high population (Thyberg & Tonjes, 2016). Agri-food production is becoming more difficult taking into consideration the excessing human demand of the world's natural capacity (Gomiero et al., 2011; Ziervogel et al., 2006; Devereux & Edwards, 2004). This leads to the issue of food insecurity, which occurs when people do not have constant physical, social, or economic access to appropriate, safe, and nutritious meals to meet their nutritional needs and food choices in order to live an active lifestyle (FAO, 2018).

Even now, 2 billion people cannot regularly reach safe, nutritious, and sufficient food with the inclusion of 8% of the population in Northern America and Europe according to the 2019 global report of the Food and Agriculture Organization of the United Nations (FAO). Moreover, according to IPCC 2019 Report, two-thirds of the world population, which is 821 million people, are still undernourished and expecting that 100 million more people will face hunger issues in terms of ongoing crises in the next decades (P. R. Shukla et al., 2019). Simultaneously, approximately one-third of the food (equivalent to around 1.3 billion tons) produced worldwide to feed people every year is lost or wasted globally (Liu, 2014; FAO, 2011). Unfortunately, 25-30% of the food produced today is lost or thrown away (P. R. Shukla et al., 2019). For instance, in Europe food waste is 180 kilograms per capita a year (Herold et al., 2019). This data is a clear indication of the inefficiency of current food systems in a world where millions of people are starving even the world is industrialized or globalized. Despite the fact that the worldwide amount of food waste is more than adequate to feed the world's poor, ironically, tons of food are thrown away every day while ready to be consumed (Melikoglu et al., 2013). In this context, the increased awareness of the "food paradox" represents a relevant social impetus, such as an ethical and moral issue, for the implementation of FLW reduction strategies.

With the COVID-19 disease that emerged in 2020, social distancing measures have drawn more attention to the risks of significant food loss, especially in dairy products, meat, fruits, and vegetables, as they cause supply chain disruptions and renewed demands (Laborde et al., 2020; Torero, 2020). In this process, the changes brought by the pandemic to the countries are supply contraction due to the seasonality of production and the lack of temporary or nomadic labor supply, price increases due to foreign trade, shrinkage in demand due to quarantine practices, and changes in consumer preferences (Ceylan & Özkan, 2020). Global food supply chains or in short FSC are experiencing major problems due to the pandemic. For example, farmers in India feed strawberries to cows because they cannot transport them to city markets. As restaurants and hotels that typically buy white cocoa are closed in Peru, growers end up dumping a lot of cocoa in landfills. For the same reason, farmers in the United States and Canada have to spill their milk. Moreover, in many countries, farmworkers who came to work from other countries to harvest the farms were stranded at the borders due to the pandemic, which caused agri-food products to rot in the fields (Torero, 2020).

As the COVID-19 pandemic progressed, catastrophic economic and food security crises emerged, resulting from income losses that hurt the world's poorest and hungry (Laborde et al., 2020). While the COVID-19 pandemic is a health issue, it is in many ways a food safety issue. Thus, with the COVID-19 pandemic, the problem of global and national food security has taken its place on the agenda of countries again. The total cost of COVID-19 worldwide is estimated to range from a minimum of $283 billion to $9.2 trillion (Maital & Barzani, 2020). However, COVID-19 has shown how fragile the global food system is, and in the current food systems in the post-COVID-19 world, it is clear that drastic changes are needed. With the COVID-19 pandemic, it is estimated that the agricultural input problems predicted by the World Bank will be felt most in developing countries (World Bank, 2020). The first of these is the trade restrictions of developed countries. While these restrictions greatly reduce the incomes of agricultural exporting developing countries, disruptions in the global food chain increase agricultural input import expenditures.

In accordance with the Turkey Waste Report 2018, prevention of food waste is an important way to prevent malnutrition which has become a major problem worldwide (Güzel et al., 2018). In order to meet the worldwide food demand for the rising up the population, it is vital that not only food production be remarkably increased, but also it is equally significant as the reasons for FLW be addressed (Balaji & Arshinder, 2016; Halloran et al., 2014).

2.2. Food Loss and Waste and Its Relations with Natural Resources

The amount of labor and resource spent on agri-food production and distribution until it reaches our table is undeniable (Balaji & Arshinder, 2016). Furthermore, not only edible foods are wasted, but also all other resources which have been used in the entire process from soil to our table are wasted, which is called the environmental footprint of food waste.

This term is classified in four different ways (FAO, 2013; Buzby & Hyman, 2012);

- Carbon Footprint
- Water Footprint
- Land Occupation/Degradation Impact
- Potential Biodiversity Impact

Carbon Footprint: Regardless of whether food is consumed or not throughout the different steps of the FSC (i.e., transportation, storage, cooking), the energy requires met by burning fossil fuels during the process causes greenhouse gas emissions (GHG). When food waste is transported to landfills, methane and carbon dioxide are released into the atmosphere through the natural decomposition process (Papargyropoulou et al., 2014). According to IPCC 2019 Report, FLW is projected to account for 8-10% of total anthropogenic carbon dioxide emissions (P. R. Shukla et al., 2019). Simultaneously, a major source of agriculture carbon footprint problem is agricultural processes such as fertilizer application or livestock production. Large environmental waste is generated from fertilizer application which over 95% of food waste is converted into methane, carbon dioxide, and other GHG through anaerobic digestion (Melikoglu et al., 2013). While fertilizer application creates direct nitrogen oxide emissions from soil operations, livestock production, it is caused by the emission in the form of methane produced by animals (Sherhaufer et al., 2018). The livestock production sector is responsible for the largest agricultural GHG, accounting for 18% of global GHG emissions in the form of methane (Herrero & Thornton, 2013). Methane, which warms the atmosphere by absorbing the sun’s heat, is in fact, a far more potent GHG than carbon dioxide. Over a 100-year time frame, methane is expected to have a 34-fold higher Global Warming Potential (GWP) than CO2 as a heat-trapping gas. In this regard, according to IPCC Report 2013, in the first two decades after the methane release, it is 84 times more potent than carbon dioxide destabilizing the climate (Stocker et al., 2013). According to FAO expects, if food waste were a country, it would rank third after the United States and China in terms of GHG emissions (FAO, 2014).

Water Footprint: Agriculture is one of the biggest consumers of water globally as a result of the massive quantities of water that need to be spent in the irrigation process. According to Organisation for Economic Co-operation and Development (OECD) report, 70% of freshwater resources are used in agriculture (Brooks et al., 2019). FLW is associated with annual water consumption of approximately 173 billion cubic meters, representing 24% of all water used for agriculture (Songür & Çakıroğlu, 2016). With the increasing population, agriculture is expanding into new regions to meet high food demands, thus increasing the water demand rapidly (Strzepek & Boehlert, 2010). The need for high efficiency is imperative in the use of water and other resources (Tzounis et al., 2017).

Land Occupation/Degradation Impact: According to the OECD Report 2019, agriculture takes up 40% of the planet's land (Brooks et al., 2019). The conversion of forests to agricultural land, for example, has a negative influence on biodiversity and increases GHG emissions in direct proportion. Also, in accordance with IPCC 2019 Report, forestry, agriculture, and other land uses are predicted to account for 23% of worldwide anthropogenic GHG emissions from 2007 to 2016. (P. R. Shukla et al., 2019). In addition, extreme practices such as spraying and irrigation can lead to desertification.

Potential Biodiversity Impact: Food waste causes increased food production to ensure consumption while increasing food production causes more land to be used for agricultural land. Deforestation, land occupation, and water pollution, these impacts partly result in biodiversity loss (Schwegler, 2014). Conversion of forests and grasslands to fields and pastures causes habitat loss, posing one of the biggest dangers to agriculture-related wildlife (Feldstein, 2017). Climate change negatively affects human health, biodiversity, ecosystem livelihoods, food and infrastructure systems. The food supply is expected to become less stable as the magnitude and frequency of extreme weather events caused by climate change rise (P. R. Shukla et al., 2019). The extent of the environmental damage caused by a product wastage depends on which stage of the supply chain that product is wasted. Along the supply chain, the later the waste occurs, the greater the extent of environmental damage. Because all associated actions and emissions made upstream in the FSC are pointless when food is wasted (Sherhaufer et al., 2018).

In this regard, unconscious resource usage, global warming, reduction of water resources, and zoning of agricultural lands is becoming a threat in order to reach enough food for the world population (Flores & Villalobos, 2020; Tzounis et al., 2017; Bright Masakha Wekesa, 2017; Sundmaeker et al., 2016; Ziervogel et al., 2006). The agricultural sector is considered to be one of the main causes of environmental degradation, as agricultural practices are not sustainable worldwide. Wasted resources liable to ecological impact, ineffective rivalry to land, and water resources make the agriculture sector crucial social significance. As a result, it is stated that reducing FLW, particularly food waste, is critical in reducing the unjustified burden on the environment and natural resources in industrialized countries (Shafiee-Jood & Cai, 2016). In this context, by reducing loss and waste, we can increase the efficiency of natural resource use and contribute to a sustainable environment.

2.3. Food Loss and Waste and Its Relations with Socioeconomic Issues

While FLW causes significant problems on nutrition and the environment, it also harms communities socioeconomically (Elijah et al., 2018; Eriksson & Spangberg, 2017; Balaji & Arshinder, 2016; Halloran et al., 2014). Particularly since agriculture is the main source of income for a big proportion of the population, FLW diminishes farmers' income and money becomes a squandered investment, in developing nations. It is expressed as wasted investments that can increase (Lipinski et al., 2013). Also, higher food prices lead to increased consumer spending and, as a result, poverty. Even in developed countries, the socio-economic damage of FLW is undeniable. Food waste at the retail and consumer level increases sales prices, limiting food access for low-income households (Beretta et al., 2013). Apart from the economic loss experienced, the amount of money spent on different activities such as purchasing, transporting from supermarkets, cooking time, and effort is wasted and considered as a waste (Songür & Çakıroğlu, 2016). Reducing waste is an important strategy to meet food demand while also lowering the ecological effect of current food production (Godfray et al., 2010). With the reduction of agricultural FLW, the environmental resources spent during the process from the farm to the table will not be wasted, meanwhile, reduce the adverse effect of human beings on nature and make it more sustainable.

2.4. Agricultural Goods and Its Relations with Perishability

The goods or commodities that are produced using plants and animals to sustain or improve human life are called agri-food products include fruits and vegetables, oilseeds, animals or livestock, dairy, cereal grains, etc. Some agri-food products are used as both a food source and an industrial ingredient. The agri-food products are categorized as perishable products with short storage life under atmospheric conditions (Mahmood et al., 2019; Li et al., 2019; Nadhori & Ahsan, 2018). Fresh agri-food products are more susceptible to spoiling in a short time (fresh fruits and vegetables, fresh meat), while grains are among the more resistant crops (Shafiee-Jood & Cai, 2016). The reasons for agri-food perishability are due to lack of information sharing, forecasting complexities, the performance evaluation based on cost, efficiency, and effectiveness (Kaipia et al., 2013; Taylor & Fearne, 2009). At this stage, although it depends on product species, it is challenging for harvested fresh agri-food products that are sensitive to temperature changes to remain intact for a long time without any precautions and under the influence of environmental conditions.

Food waste occurs from not paying due attention and acting unconsciously (Lipinski et al., 2013). Damage, loss, or wastage occurs in products due to deterioration that occurs directly linked to human action or inaction. In fact, while damage indicates that a product will not be used as efficiently as it was originally, loss indicates that the product becomes unusable (Kiaya, 2014).

2.5. Definitional Framework of Food Loss and Waste

Before addressing successful ways and tactics for reducing food waste, it is vital to have a thorough understanding of what the term “food waste” entails. Some studies make a definite distinction between “food loss” and “food waste”. In accordance with the definition of FAO, food loss refers to decreasing weight or volume in edible food or the nutrient value of the food, whereas food waste refers to food that is disposed of after the expiration date has passed or left to deteriorate (FAO, 2013). Based on Parfitt et al., the FAO suggested a distinction between food loss and food waste considering the FSC phases (2010). Food loss occurs during the first stage of the FSC, namely agricultural production, post-harvest processing, or processing. Food wastage occurs at the end of the FSC, namely during distribution, retail sales and, final consumption. Throughout the FSC, food loss and waste are investigated or, in other words, post-harvest systems (Salihoglu et al., 2018 & Gustavsson et al., 2011). Other studies have adopted the “food waste” considering “food loss” synonymously as “food waste”, in order to approach to refer to any food lost by deterioration or waste. In this regard, the term food waste in these studies includes referring to both food loss and food waste (Stenmarck et al., 2016).

While most organizations define food waste, only agri-food products intended for direct human consumption are taken into account (FAO, 2014; Stenmarck et al., 2016). In contrast, there is another view in the literature that food waste should not be based solely on human consumption, since the products (shell, bones, leftovers) that emerge after humans consume food are used in the non-human agri-food production chain (intended for animal feed or non-food uses). Products planned for human consumption but given to animals as food due to specific consumer preferences can be counted as “lost” because humans do not consume them, but this contributes to the production of food of animal origin (Koester, 2014). Products called lost for non-human use can be efficiently used non-food in an area other than the FSC, such as biofuel production (FAO, 2019). In this view, animal feed or non-food agri-food products that can be used efficiently in other fields (bioenergy, biomaterial, and industrial systems, etc.) are not considered as waste (Chaboud & Daviron, 2017).

Since the definition of food waste is frequently disputable, several distinct definitions have emerged as avoidable/inevitable. To accurately estimate the potential for food waste reduction, a division among both avoidable and unavoidable food waste must first be formed (Huber-Humer et al., 2017). Despite the fact that the distinction between avoidable and unavoidable food waste is widely utilized in the literature, it is nevertheless applied contradictory (Lebersorger & Schneider, 2011). Research generally agrees that avoidable food waste can be defined as products that are in an edible state and have not been used ultimately, and are partially consumed (Lebersorger & Schneider, 2011). Examples of these foods are products that consist of foods prepared for consumption but not eaten (e.g., cooked rice) or food that has been left to spoil (e.g., rotten fruit and vegetables). Unavoidable food waste refers to waste generated during food preparation: which are generally not preferred (shells, bones, etc.) by people to eat but are not considered edible (Bernstad Saraiva Schott et al., 2013). Agri-food products that are planned to be consumed can be defined as unavoidable food waste because of the necessity of shrinking during storage due to seasonality, high harvest costs, or remaining in the field due to certain consumer preferences (Koester, 2014).

Food loss and waste definitions are handled on three criteria: use and target of food goods, edible aspect of food products, and nutritional value of food products (Chaboud & Daviron, 2017). The utilization criterion considers the use and destination of food that is not consumed by humans, such as a landfill, energy production, bio-material processing, livestock feed, manure, and so on (Chaboud & Daviron, 2017). The second criterion is to make a distinction between edible and inedible food waste. Some FLW definitions include consumable and conceivably consumable elements of food items (Salihoglu et al., 2018; Gustavsson et al., 2011, Ventour, 2008), while others do not discriminate between edible and inedible sections of food products (Stenmarck et al., 2016). While the FAO and Economic Research Service's (ERS) definitions only apply to edible, safe, and nutritious foods, the Food Use for Social Innovation by Optimising Waste Prevention Strategies Project (FUSIONS), and Environmental Protection Agency (EPA) definitions apply to both the edible and inedible parts of the food (Bellemare et al., 2017). The last criterion is the food nutritional value, which is made up of a variety of macronutrients (proteins, carbs, fiber) and micronutrients (vitamins and minerals) that are necessary for human growth, progress, and well-being. The calories from Wasted Nutrition Days and wasted diet days embedded in per capita daily food waste are analyzed in studies based on nutritional value loss. According to such studies, food waste consumes an average of 273 kcal of energy (calories) per person per day worldwide (Chen et al., 2020).

Furthermore, in accordance with the FAO, the FLW definition can be based on a quantitative or qualitative basis. Quantitative, which can be defined as physical FLW, refers to removing the food from the FSC due to the volume and mass loss of food intended for human consumption. Qualitative refers to the decrease in food attributes (nutritional value and/or economic value due to quality standards) that reduce its value in terms of intended use. Both types of FLW are the outcome of decisions and behaviors made by vendors, caterers, and customers (FAO, 2019). Furthermore, quantitative appears to be prevalent among emerging countries, while qualitative FLW is prevalent in industrialized countries (FAO, 2014). Although FLW does not have a standard description the literature contains various definitions of organizations to date.

In accordance with the FAO, food waste is described as follows: “Food waste is defined as ‘the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services and consumers. 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”. (FAO, 2019)

The United States Department of Agriculture’s (USDA) and ERS define food waste as follows: “Food loss represents the edible amount of food, postharvest, available for human consumption but not consumed for any reason. It includes loss from mold, pests, or inadequate climate control, cooking loss and natural shrinkage (for example, moisture loss), food waste”. (Buzby et al., 2014)

The European Union (EU) project called FUSIONS, which is defined as “a work project for a more resource-efficient Europe by significantly reducing food waste”, defines food waste as follows: “Food waste is any food, and inedible parts of food removed from the FSC” to be recovered or disposed of (including- composted, crops ploughed in/not harvested, anaerobic digestion, bioenergy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)”. (FUSIONS, 2016)

Finally, The EPA represents the food waste as follows: “Food waste refers to food such as plate waste (i.e., food that has been served but not eaten), spoiled food, or peels and rinds considered inedible that are managed in a variety of methods other than a donation to feed people. The amount of food going to landfills from residences, commercial establishments (e.g., grocery stores and restaurants), institutional sources (e.g., school cafeterias), and industrial sources (e.g., factory lunchrooms)”. (EPA, 2018)

On the other hand, FLW is only examined in this paper in regard as agri-food products that are intended for human consumption but are not suitable for human consumption for any reason during the stages of the FSC (i.e., harvesting, distribution, packaging, storage), have deteriorated, or have lost their nutritional value, but can then be evaluated according to use criteria (i.e., animal feed, bio-energy production, fertilizer).

2.6. Classification of Food Loss and Waste in Food Supply Chain

Today's social awareness has made the management of FSCs an important local and global issue. FSCs are essential for their significant contribution to the economy of any country and to the well-being of the nation (Ali et al., 2019). Although these losses cannot be totally avoided, the solution to the food safety problem necessitates a move from limited production-oriented methods to a broader approach that considers the efficiency of the entire FSC (Shefiee & Cai, 2016). In general, although the supply chain is defined as farm-to-table, supply chains become much more complex as products rush around the world due to the products can be resold and repackaged before they reach the last consumer (Minor et al., 2020). Inadequate management during logistics for such products poses a high risk for food safety. Moreover, in spite of food waste is frequently associated with final consumption, the conscious disposal of food can occur at all stages of the FSC, such as harvest, transport, storage, packaging, processing, wholesale and retail stages (Balaji & Arshinder, 2016; Sundmaeker et al., 2016; Gustavsson et al., 2011). In 2016, in Europe and North America, 20% of food waste, including losses in agriculture, occurs in the FSC (Liegeard & Manning, 2020).

Damages resulting from pre-harvest circumstances and field operations may have an indirect impact on losses in the latter stages of the chain (FAO, 2020). Sometimes, these losses can occur for economic reasons such as harvest failure, low market price, and excessive labor costs over the same time period. Some causes of food losses in the field pre-harvest; biological and biotic factors such as not being able to follow meteorological forecasts, not having soil analysis, not following appropriate pesticide applications, and planning the timing of harvest, weeds, insect pests, and diseases can be given as examples (FAO, 2020). Despite the fact that the magnitude of these losses is significant, they are not included in the definition of "food loss and waste." (FAO, 2020).

Agri-food production, harvesting, and post-harvest operations cover the ongoing process where the crop is still on the farm or in its facilities. Post-harvest operations include cleaning, classification, sorting, and operations. Primary and secondary processing are the two types of processing. Primary processing usually takes place on the farm processes such as drying, dehusking, deshelling, etc. Secondary processing can be called product transformation. The point at which food is consumed or withdrawn from the FSC is known as the chain's endpoint (FAO, 2019). These external factors during the FSC contribute to Post-Harvest Loss (PHL) by causing loss and waste. PHL levels are between 30% to 40% and half of this waste occurs before food reaches consumers (Hochfelder, 2017). The food produced for human use becomes unsuitable for human consumption as a result of a change in availability, integrity, or quality is called PHL. There are many reasons for food waste to occur. The term PHL refers to measurable in both quantitative and qualitative food loss from harvest to consumption (Kiaya, 2014). To get a better understanding of the overall effects of food waste and, as a result, to identify crucial points for future prevention efforts, it is necessary to determine in detail where and for what reason waste occurs along the supply chain. FLW may occur for different reasons at each stage in the FSC process from field to table.

FLW causes occurring throughout the food supply chain are classified according to the different stages of the FSC:

- FLW in Harvesting Process
- FLW in Handling and Storage Process
- FLW in Distribution Process
- FLW in Processing and Packing Process
- FLW in Retailing Process
- FLW in Public and Households Consumption Process

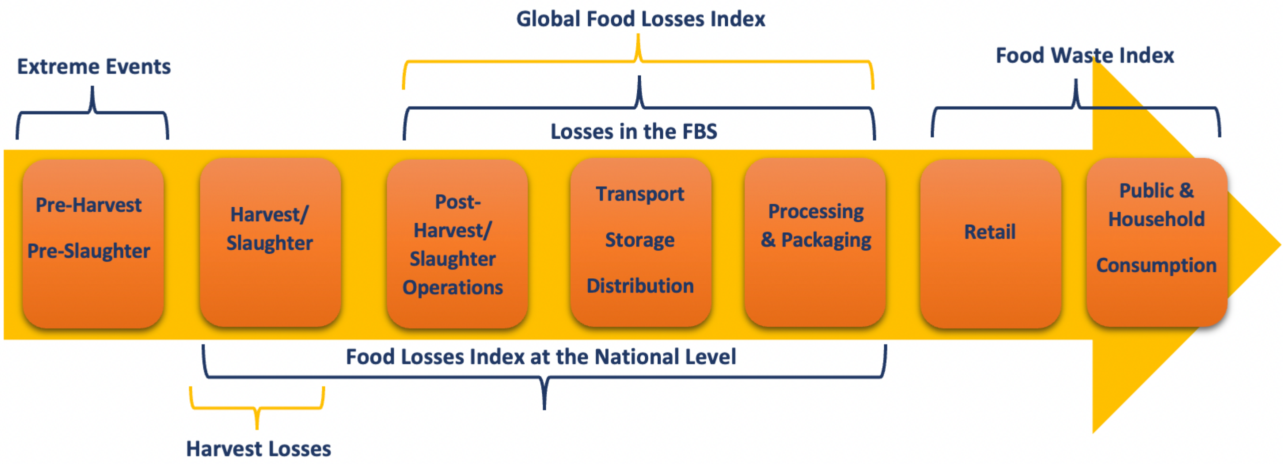

Figure 2.6. The Functional Framework of Global Food Loss and Waste (Resource: Global Food Losses Index)

2.6.1. Food Loss and Waste in Harvesting Process

Edible crops planned for consumption but left in the field due to lack of demand or high harvesting costs due to failing to meet certain quality standards set by target markets, loss of harvest food quality eaten by birds, rodents, pests, unpredictable weather conditions, damage from the disease are examples of losses during production or after harvesting. Incorrect planning of the harvest time and improper packaging of the product immediately after harvest (i.e., not keeping it at the required temperature and humidity level) cause serious product deterioration later in the value chain (FAO, 2020).

2.6.2. Food Loss and Waste in Handling and Storage Process

Insufficient warehousing conditions are the significant reason for the loss of food products at the phase of production and distribution (Lipinska et al., 2019). After harvest, the storage temperature and humidity are calibrated so that the fruits remain fresh with minimal spoilage. Improper storage temperatures can increase respiration and dehydration, leading to premature fruit ripening (Alam et al., 2021). The large majority share of those losses is concerned with non-optimized handling throughout the FSC processes (Jedermann et al., 2014). Not just for storage and onward migration, but also for grouping/sorting shipments, quality monitoring, stock control, and other activities, the supply chain always comprises a hierarchy of distribution centers (Pal & Kant, 2020). However, even if the products are stored in the best conditions, some faulty practices (i.e., the shelf life of the products, wrong harvesting technique, time under the sun) may damage the products.

2.6.3. Food Loss and Waste in Distribution Process

Shipping and distribution require a complex interaction of many processes to efficiently move products from manufacturers to customers. A significant percentage of agri-food is becoming waste due to the imperfect distribution process (Kaipia et al., 2013; Mena et al., 2011; Griffin et al., 2009). Failure to prepare a good shipment program, not paying attention to certain stock levels and storage conditions of products (humidity, etc.), lack of effective ventilation, pest and rodent formation in warehouses, and failure to take necessary precautions can be shown as substances that cause FLW.

Inappropriate vehicle loading and unloading methods, poor or incorrect packaging, long transportation processes, uneven road structures, inadequate cooling, and humidity regulation systems during transportation, uncontrolled movement of products in the vehicle, not pre-cooling before loading, transportation of products that are not suitable for transportation together, losses caused by the driver of the vehicle could be given as an example of the causes of food loss during distribution process (FAO, 2020).

2.6.4. Food Loss and Waste in Processing and Packing Process

During the processing stage, food losses are usually caused by production-related technical faults and inefficiencies. Although mistakes made during processing (i.e., incorrect size, weight, form, look, or damaged packaging) in the finished product has no effect on the food quality or safety, foods that do not meet the standards may have to be discarded (FAO, 2020). In the industrial use of food or in domestic processing, losses occur during slicing, peeling, boiling, and washing of crops, as well as during process interruptions and unintentional spills and spoilage (FAO, 2011). Packing damages, nonconformity with food safety requirements, disregard of the expiry date, poor stock management, marketing strategies, and logistics limitation cause rising food losses during the distribution process (Priefer et al., 2016).

2.6.5. Food Loss and Waste in Retailing Process

The agri-food industry is more and more structured around worldwide value chains led by food processors and retailers (De Backer & Miroudot, 2014). Supermarkets are the most important intermediary between the farmers who produce from the field and the consumers who can access the same product from the market. The large supermarket chains discard edible more fresh fruit and vegetable as their sales strategy, which ensures quality and food safety standards to sell only premium products. Due to the agreement between the supplier and the retailer to return unsold products, large quantities of products are withdrawn from the sale a few days before the expiry date is reached (Cicatiello et al., 2016). While food waste in the retail industry refers to unsold products that need to be disposed of or recycled, the fact that most of the discarded products are still suitable for consumption indicates the ethical dimension of these wastes (Teller et al., 2018). In the retail sector, food waste is often caused by inappropriate orders or incorrect sales estimates (Cicatiello et al., 2016). Almost a third of fresh fruits and vegetables never reach supermarket shelves due to high supermarket standards (Dittmer et al., 2012; Porter et al., 2018). Generally, in supermarkets, food waste consists of about 50% of vegetables, 30% fruits, 9% grains, and the remaining 11% dairy products (Salhofer et al., 2008). Retailers offer a large selection of food products in a wide assortment, as consumers want grocery aisles to be stocked with a wide variety of products. Stock and surplus supply are another significant source of food waste in this context. In the retail phase, apart from supermarkets and wholesale places, commercial establishments (grocery stores, restaurants and hospitality sector, etc.), institutions (education institutions, hospitals, cafeterias, prisons, etc.), and industrial sources (factory lunchrooms, etc.) other similar food services are also included, as well as shops. Lack of production planning, inadequate stock management, unfavorable hygiene conditions, personnel uneducated, lack of alternative portions and open buffet applications, refreshments offered to the consumer without being asked, consumers by touching when choosing fresh fruits and vegetables to harm, near expiration date approaching inability to sell can be given as an example where food waste occurs by the attitudes of these organizations (FAO, 2020). Food waste in commercial establishments, institutions, and industrial sources arises from the internal organization and customer service (Calvo-Porral et al., 2017). In catering services, food is often considered the lowest-cost resource and is often seen as disposable, while restaurants deliberately order too many items to prevent running out (Garrone et al., 2014). Incorrect planning of the meals and the number of meals to be served leads to food waste. Furthermore, most food waste occurs when restaurants and caterers do not reuse food that has been prepared but not yet served (Garrone et al., 2014). Considering the reasons for food loss on a commercial enterprise basis, overproduction, improperly planned menus, and portions, non-standardized food production, unattended hygiene rules, inadequate storage, unconscious behavior of staff, unsatisfied consumer plate waste may be counted as the cause of FLW in this process.

2.6.6. Food Loss and Waste in Public and Households Consumption Process

One of the most important roles in FLW in final consumption belongs to household food waste, which has the significant share in FLW, is determined by the consumer’s behavior at various stages (i.e., planning, food purchase, storage, preparation, consumption, and disposal) (Principato, 2018). Consumer-level food waste mainly results from the attitudes and behavior of consumers (Principato, 2018; Partifitt et al., 2010). Situational factors, social norms, psychological factors, and socio-demographic characteristics have an impact on consumer behavior (Aschemann-Witzel et al., 2015). The occurrence of food waste may differ due to three different factors, according to society, person, and year, respectively (Thyberg & Tonjes, 2016). Moreover, countless families are uninformed of the amount of food waste that is happening in their homes. The most important cause of food waste in households is the food that is thrown away since the recommended consumption date has passed. Other sources of food waste arise because of more prepared than can be purchased and consumed, but not consumed on time (Garrone et al., 2014). The sectors that contributed the most to food waste in Europe in 2012 are households, with 47 million tons corresponding to 53% of waste. In Europe, more than 50% of post-harvest food waste occurs at the consumption stage (Stancu et al., 2016). Domestic food waste accounts for two-thirds of the total waste cost (approximately 98 billion Euros) (Stenmarck et al., 2016).

2.7. Food Loss and Waste Perspective in Developed and Developing Countries in Food Supply Chain

In general, the exact causes of FLW vary and are highly dependent on the particular circumstances and local situation in a particular country (FAO, 2011). FLW percentages in total food produced, although almost equal in developed and developing regions (varies between 28% and 36%) (Shafiee-Jood & Cai, 2016). But the distribution of this FLW differs significantly between developed and developing countries. In medium and high-income countries, major losses occur at later stages of FSC and are particularly pronounced at retail and consumption, meaning that it is discarded even if it is still appropriate for human consumption (Gustavsson et al., 2011). At this age, with the developments in the agriculture and food industry, the production volume of food products increased in many developed countries and this development allowed them to overcome food deficits (Parfitt et al., 2010). This situation affects the amount of FLW produced by retailers, as higher living standards among consumers in developed countries correspond to higher quality and aesthetic standards of food products (Thi et al., 2015; FAO, 2013). On the one hand, the uncertainty of producers' planning in quantity orders contributes to excess stocks and leads to the production of more food than necessary (Schneider, 2013). Many harmful microorganisms can infect fresh produce, especially due to improper handling and handling practices, due to the potential significance of these hazards, regulations on fresh fruit are strict, especially in developed countries (Alam et al., 2021). For instance, European legislation includes certain marketing principles for fruit and vegetables related to aesthetic (imperfect shapes or appearances) rather than food safety purposes (Garske et al., 2020; Canali et al., 2017). Another problem that causes FLW in developed countries is to misinterpret the expiry date labels placed on foods to ensure food safety and throw away foods that can be consumed (Garske et al., 2020). According to FAO research, it turns out that the volume of wasted food in industrialized countries is almost the same as the volume of all food produced by Sub-Saharan Africa (FAO, 2011). As a result, the ease of access to various foods, the decrease in food prices due to high production, and the low share of household expenses in food shopping led to an increase in food waste. While the amount of food per capita wasted during the consumption phase is around 95-115 kilograms per year in developed countries, it is roughly only 6-11 kilograms per year for developing regions (Gustavsson et al., 2011). However, in low-income countries, food is often lost in the initial and halfway phases of the supply chain due to technical, managerial, and financial constraints (Gustavsson et al., 2011).

In developing economies, food is largely wasted quantitative basis caused by a lack of modern and inadequate logistics infrastructure such as poor transport, deficient cooling technologies, inappropriate marketing network (Shafiee-Jood & Cai, 2016; Chrobog, 2014). It is predicted that the FLW rate in developing countries will increase in direct proportion to the country's increasing population and growing economies in the coming years (Melikoglu et al., 2013). Given the lack of technologies used in agriculture in developing countries, grains are highly vulnerable to harsh environmental conditions, especially in a humid climate, while grains generally have very low loss rates in developed countries (Shafiee-Jood & Cai, 2016). Every year, 14% of the world's food is lost during the FSC processes (FAO, 2019). Only Europe lost 28% of fresh fruits and vegetables. Considering the possibility that wasted food can be recovered, the severity of the situation manifests itself more.

Therefore, supply chain management (SCM) is getting become a more significant concept in the agriculture sector in order to transport agri-food products efficiently from rural production areas to consumers, generally live in urban areas, to abstain from food and quality losses (Leithner & Fikar, 2019; Jedermann et al., 2014; Parfitt et al., 2010). Ensuring the flow of data and materials at the same time is crucial while improving the viable performance of the supply chain (Kaipia et al., 2013).

2.8. Perspective of Agricultural Food Loss and Waste in Turkey

Agriculture is one of the most important sources of income for emerging countries. Hence, agriculture plays a significant role in the economic and social development of Turkey, which is located in a strategic geopolitical position, owning to product varies according to the climate diversity characteristics, fertile agricultural lands, endemic species richness, ease of access to world markets. In Turkey, which agriculture constitutes 6.3% of GDP and has employed 19% of the workforce, every year up to 120 million tons of agri-food products are produced by meeting 80 million of the country's population nutrition needs in order to provide continuation of the generation. With respect to long-range predictions, United Nations is expected that Turkey's population is to reach 97 million by 2060 (European Union, 2018). However, meeting the existing demand for food, as it becomes a problem worldwide due to the growing trend in the population, is becoming a problem for Turkey as well. Agriculture in Turkey is a sector that has been shrinking recently. Moreover, since its profitability has decreased in the recent period, it is evolving into a sector that rapidly migrates and will soon have difficulties in finding producers. The biggest problem is the aging population and young people's lack of interest in this business.

Another problem is that despite Turkey's agri-food production potential, it is not at the desired level in terms of food security. Turkey, which ranks 41st among 113 countries according to the Global Food Security Index, is not at the desired level in terms of nutritional standard quality, efficient food production, and food price stability (Global Food Security Index, 2020). Perishable agri-food products in Turkey suffer considerable losses from the field to the table. In accordance with data of the Scientific and Technological Research Council of Turkey, 25%-40% of 49 million tons of agri-food are lost in Turkey every year. Therefore, it has a considerable economic impact on Turkey's economy. As in the world, in Turkey, agri-food production is an economic activity mainly depending on natural conditions, risk, and uncertainty which lead to a decrease in productivity in agri-food production. In addition to their ever-increasing domestic demands, in developing countries that have a potential for agri-food production, a sufficient production increase cannot be achieved since they produce with traditional methods (Tuna, 2011). Reaching the border point of arable land in countries meeting the demand for agriculture and the decrease in the possibilities to improve agri-food production emphasizes the importance of the problem.

Besides the factors that cause insufficient yield in agri-food production, the supply chain, which does not perform agri-food production and distribution comprehensively, also has a large share in FLW. Overall, the distribution of FLW is more common in developing countries during the production and transportation, and storage processes (Lipinski et al., 2013). FLW occurs mostly being a lack of infrastructure in the phases of production, storage, processing, distribution, and marketing in emerging countries (Prusky, 2011; Dijksma, 2015; Demirbas, 2018). FLW occurs based on both quantitative and qualitative, especially during the FSC after the harvest period. Post-harvest FLW is determined in fruits and vegetables (33%) and oilseeds and legumes (17%) in Turkey (Tatlıdil et al., 2013). Another major phase that causes significant food losses is distribution.

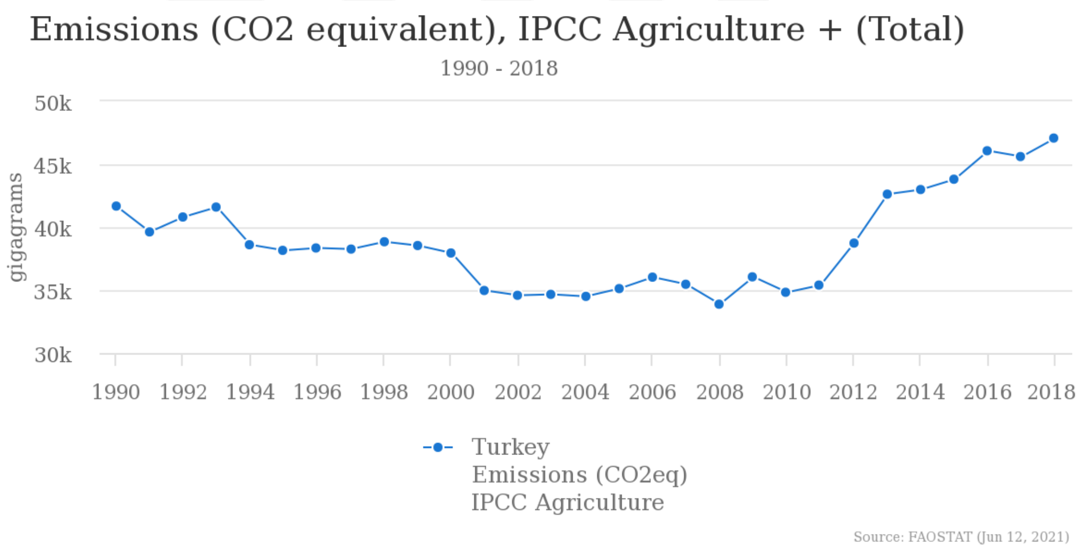

Figure 2.8. Agriculture Emissions of Turkey (Adopted from FOASTAT)

In Turkey, 2.25 million tons of food is wasted in a year during the distribution process (Salihoglu et al., 2018). According to the Intergovernmental Panel on Climate Change (IPCC) report, the amount of CO_2 emissions resulting from agri-food production in Turkey was measured as the highest amount since 1990 as 47.081.57 in 2018.

Reducing FLW in Turkey stands out as an important necessity. Food safety and loss must be prevented at every stage of the FSC. Preserving agri-food and preventing spoilage from farm to fork is a major determinant (Kazancoglu et al., 2018). The most important contribution will be made by the use of digital technologies throughout the supply chain, in the prevention of loss and waste, as well as the measures to be taken from raising seeds and soil to the use of fertilizers and other materials.

Turkey became a member of FAO in 1948 and the institution established its first country office in Ankara in 1982. FAO Turkey supports the government and stakeholders in establishing policies and programs related to food safety and nutrition, as well as food safety, in order to improve food safety, availability, accessibility, reliability, and quality at all stages of the food chain and also to promote the dissemination of sustainable natural resource management technologies and innovative production technologies and methods (FAO Turkey, n.d.). With the initiatives of Turkey, the "Technical Platform for Measuring and Reducing Food Loss and Waste" was established at the United Nations FAO Headquarters in Rome (FAO, 2020). Also, In 2020, under the coordination of the Turkish Ministry of Agriculture and Forestry and in cooperation with the FAO, a large-scale national campaign called "Save Food" was launched to reduce FLW (FAO, 2020). Understanding these factors will aid them in redesigning the process and achieving operational gains by utilizing the capabilities of new technology in the FSC.

In the next section, the study will continue with examining the IoT-based technologies and the relationship of IoT with the smart supply chain to determine the effect of reducing FLW.

CHAPTER 3
THE IMPORTANCE OF APPLYING INTERNET OF THINGS IN REDUCING FOOD LOSS AND WASTE

With the developing technology and increasing population, in industrialized countries, a growing number of products and services are created and consumed. This directly affects the amount of waste produced in the right proportion. Despite the widespread usage of the terms “waste prevention” and “waste minimization”, there are no exact definitions for these concepts, making it impossible to distinguish between them (Salhofer et al., 2008). Preventing food waste avoids unnecessary use of natural resources from the very beginning of the process. This is why it is the most preferred method compared to all other waste reduction options (Messner et al., 2020). By reducing FLW, we can prevent food waste and increase food security and reduce unethical behavior, increase the efficiency of existing resource use and contribute to a sustainable environment (Koester, 2014). At the Berlin meeting in 1996, the OECD has expanded the definition of “waste prevention” to include the concept of “waste minimization”, which includes not only measures aimed at reducing waste after it is generated, but also measures before waste is generated (Salhofer et al., 2008). Preventive measures cover “prevention”, “reduction at source”, and the “reuse of products”, while waste minimization as well as includes the waste management measures of “quality improvements” and “recycling” (EEA, 2002).

3.1. Agriculture Modernization and Its Relations with Food Loss and Waste Reduction

Until today, agriculture has seen plenty of changes and improvements within the distinctive farming approaches and techniques. In order to meet the growing population needs, farming companies have started to continue with the new methods aside from the traditional techniques which they have applied so for. Over the years, technology has been demonstrated to be greatly valuable within the agricultural sector. In fact, agriculture is getting adapted into the modern world with the advancement of both information and technology from past to present (Sundmaeker et al., 2016). The two most important factors creating the need for modernization and intensification of agricultural practices are the continuous increase in the world population and the increasing demand of people for high-quality products. To deal with these impacts, an efficient global food system is needed for humankind based on sustainability. Agriculture 4.0 is a novel concept that has emerged in recent years (Corallo et al., 2018). Data management and digitalization of data in food and agriculture systems are also discussed in Agriculture 4.0. The system is powered by AI, IoT, and automation, with the goal of establishing a network of connected farms, equipment, and factories, as well as attaining high levels of system optimization on both the supply and demand sides (Rezek et al., 2021).

Increasing knowledge and rapidly developing technology has led to “modern agriculture”, which includes marketing, processing, distribution of agri-food products, etc. This can be attributed to the fact that the reason modern agriculture application is so important is that without them, farmers would never be able to supply the demand of food for the entire people all over the world. Modern agriculture brings excellent economic and social benefits. Moreover, social and economic factors affect the adaption speed of agricultural technologies in order to have an influence on the possibility of a farmer in order to internalize the modern agricultural technologies. While economic factors cover land size, cost, and advantage of the technology, social factors farmers’ education level, age, gender, social groupings.

Although industrial agricultural practices allow large amounts of food to be delivered to global markets, this mode of production also has negative consequences. In these practices, agricultural land productivity decreases, freshwater resources are wasted, ecosystems are damaged, GHG emissions increase, and biodiversity decrease. Industrial farming is also input-intensive; It is dependent on the prices of energy, fertilizers, and pesticides. In many countries, these inputs are imported. Therefore, less recourse to agro-industrial practices improves both the sustainability of food systems and possible trade and supply increase its flexibility by reducing its foreign dependency in chain shocks will increase.

New technologies can not only be evaluated in terms of system productivity but also in terms of precision agricultural solutions that can potentially represent innovative technologies to prevent surplus food and combat food poverty before the harvest phase

(Ambler-Edwards et al., 2009). Precision farming refers to the agricultural management that aims to protect the soil and other natural resources while increasing the yield by using the most suitable inputs like water, fertilizer, pesticide. In this method, data provided by satellite technologies are used by small, inexpensive but capable sensors, cameras, unmanned aerial vehicles, and robotic by using agricultural tools, more economical and environmentally friendly production is provided. There is a tendency towards a transition from industrial agricultural practices to precision farming practices in the world. FLW is critical in attempts to address hunger, not only in underdeveloped nations but also in rich countries because it is economically preventable (Beretta et al., 2013). Reducing FLW would boost current food supplies while also bolstering global food security (FAO, 2017). Thus, it is essential to diminish agricultural FLW in the supply chain in order to brace global food security and gain agricultural sustainability advantage taking into consideration environmental, social, and economic factors.

3.1.1. Food Loss and Waste Reduction and Its Relations with Sustainability

The reduction of waste contributes to sustainability. Sustainable development is defined as the process of fulfilling the requirements of the current generation without jeopardizing future generations' ability to meet their own needs (Brundtland, 1987). It includes questions about how to reduce the FLW in terms of sustainability, as well as how to transform and reuse it (Chabound & Daviron, 2017). An integrated and innovative approach is needed to ensure sustainable food production and consumption (Kiaya, 2014). Food waste reduction is one of the most pressing concerns for food systems' long-term viability (Ciccullo et al., 2021). It is vital to create solutions to provide much more food with much less input in order for the world's food system to offer greater nutritional benefits at a reduced ecological impact (Garnett, 2014). The Circular Economy paradigm has made a huge impact around the world as it provides diversified resolutions to combat food waste, regarding practices and approaches that combine technological solutions, behavioral and cultural changes, and policy suggestions (Vilariño et al., 2017). Technological solutions are an important part of this type of approach (Ciccullo et al., 2021).

3.2. Scope of Food Loss and Waste's Historical Development Around the World

Various national and international initiatives have been undertaken in the past to institutionalize waste minimization and waste prevention by establishing legal rules to assure effective waste prevention (Salhofer et al., 2008). From a nutritional perspective, one of the first pieces of scientific literature containing information on wasted foods from households was published by Atwater in 1895 (Schneider, 2013). With the establishment of FAO in 1945, the main objectives were to reduce food losses. It is stated that the first World Food Conference (Rome) held in 1974 included reducing post-harvest losses as part of the solution to the global hunger problem. In 2010, Parfitt et al., stated that no progress had been made towards this target (Thyberg & Tonjes, 2016). In 2000, Waste & Resources Action Programme (WRAP) was founded as a nonprofit company backed by the United Kingdom's four national governments and funding from the EU. It was instrumental in placing the issue of food waste on the public and policy agenda in the United Kingdom while advocating practical solutions based on resource efficiency as well as any waste (Evans et al., 2012). FAO published the results of its first studies on the scope and causes of global food waste in 2011. Contrary to the certain United Kingdom and EU rhetoric about food waste, FAO moves away from the notion that food waste is a problem that only needs to be managed at the household and consumer level and accepts waste from food production processes more broadly (Evans et al., 2012). After this awareness, more research is being conducted to better understand and combat food waste caused by economic, social, ethical, and environmental factors along the supply chain. Many organizations around the world agreed that it would be beneficial to tackle the scale and complexity of the food loss problem and reduce it, and beyond that, many key organizations have collaborated and implemented projects to reduce FLW. The issue of food waste has been gaining attention in the media and in the public and private sector recently (Feldstein, 2017). The Save Food initiative is a global initiative carried out under the leadership of FAO in partnership with Messe Dusseldorf, which focuses on countries in the neediest, aiming to reduce FLW, and is one of the most important activities to reduce food losses (FAO, 2018).

For the first time in EU food legislation history, the European Commission considered food waste as the key to achieving sustainability by comprehensively addressing food sustainability from primary production to consumer within the framework of the new Farm to Fork Strategy (Schebesta & Candel, 2020). The USDA and the EPA have established a target of halving FLW in the United States by 2030. The United Nations has set a similar vision for global food waste in its Sustainable Development Goals (SDGs). The EPA emphasizes the financial effects of food waste and urges food companies, the service industry, and retailers, and to decrease food waste in order to save money (Papargyropoulou et al., 2014). The Goal 12.3 of the UN SDGs, the target is an important step towards sustainable agriculture, providing food security and increasing nutrition, and supporting, ending hunger (Huber-Humer et al., 2017). SDGs aim to reduce food waste halve per capita at the retail and consumer level, as well as to reduce food losses in production and global FSCs and agriculture systems by 2030 compared to 2015 (Herold et al., 2019; Scherhaufer et al., 2018). Furthermore, SDGs are an important step towards reducing environmental impacts caused by food waste. Since the early '90s, many international organizations have taken steps in the fields of food security, reduction of food waste, improving nutrition, and promoting sustainable agriculture. However, thanks to the increased awareness of the harm of food waste to humanity, governments have taken their place at the forefront in the fight against food waste, as well as such organizations, and this struggle has gained momentum by initiating studies to reveal developments to combat food waste. While such developments and structured policies are encouraging, more work needs to be done to reduce food waste.

3.3. The Role of Smart Supply Chain in Reducing Food Loss and Waste

In recent years, measures have been proposed to reduce or prevent food waste, many of which have been implemented. The smooth transportation of extremely perishable fresh products from farm to consumer without any reduction in product quality involves the use of some infrastructure and advanced technologies, such as vacuum cooling, packaging, refrigerated transport, and storage (Minor et al., 2019). With the emergence of the COVID-19, which has been dubbed one of the most devastating pandemics the world has ever faced, all major industries, from education to manufacturing, are exploring new ways to digitize their operations (Shao et al., 2021). Technology is viewed as a potent strategic weapon that can be used to assure operating efficiency and consistency by integrating processes in smart factories (Shao et al., 2021). According to surveys by Pricewaterhouse Coopers (PwC), the multinational professional services network of firms, 50% of German businesses use SMART networking and 20% already use Industry 4.0 (Ivanov et al., 2016). The integration of the digital and physical world provides deep transformation potential for global supply chains (Wu et al., 2016). The application of technological integration in the supply chain has led to novel solutions in recent years such as shelves, containers, ports, storage, and manufacturing that can be defined as intelligent (Tu, 2018). Smart Supply Chain Management would also bring benefits through the physical flow and order management processes, which would be technologically integrated such as real-time re-planning and vendor inventory monitoring, automation of warehousing, human-machine interfaces, autonomous smart vehicles, reliable online order monitoring, SMART logistics planning algorithms (Chaopaisarn & Woschank, 2019).

Smart Supply Chain (SSC) possesses six different characteristics presented hereunder (Wu et al., 2016).

- **Instrumented:** using of machines with sensors or RFID tags to collect data in the next-generation supply chain.
- **Interconnected:** the network of linked corporate organizations and resources in an SSC.
- **Intelligent:** in order to optimize performance, SSC makes large-scale optimal decisions.
- **Automated:** most process flows in SSCs should be automated, with machines replacing low-efficiency resources like labor.
- **Integrated:** real-time cooperation across phases of a supply chain to make shared choices, share information, and create common systems.
- **Innovative:** the creation of new values in response to changing demands and requirements. SCM is nonetheless associated with the causes of food waste, but it may also help to decrease it (Liljestrand, 2017).

The supply chain needs to become much smarter in order to effectively deal with increasing challenges due to globalization and increasing customer demand in line with the massive population growth (Butner, 2010). Smart Supply Chain Management refers to "having the right product item in the right quantity at the right time at the right place for the right price in the right condition to the right customer" (Wu et al., 2016). However, the FSC needs to be more responsive in the early stages of the supply chain and more efficient in later stages (Blackburn et al., 2004).

Perception, transmission network, communication, and application are the four layers of an IoT system's architecture (Farooq et al., 2015). Perception is the use of technology like mobile communications, actuators, controllers, sensors, 2D barcodes, Electronic Data Interchange (EDI), and RFID tags in logistics. Also, a cloud database, device modeling, gateway control, secure wireless networks, Bluetooth, and ethernet are all part of the transmission network. Ultimately, communication and implementation are the outputs provided by the IoT system on monitoring, diagnosing, and analyzing stages in the supply chain (Chaopaisarn & Woschank, 2019).

3.4. The Role of Internet of Things in Reducing Food Loss and Waste

The IoT is a data gathering and transmission infrastructure that can have a substantial impact on system efficiency and performance (Jagtap et al., 2021). The basic goal of the IoT is to develop a structure for the interchange of goods, services, and knowledge (Tu, 2018). One of the most significant advantages of the IoT is to tackle the issues where man kind's intervention is not at all feasible. Reducing FLW in the FSC has also become a major application field in the industrial sector, academia in terms of IoT technology capability. What makes FSC different from all other types of supply chains is that it handles complicated challenges including the perishable nature of a commodity, contact with a large number of stakeholders, and, so on and cross-industry impact (Chen et al., 2020; Ali et al., 2019). As the number of members in the FSC grows and becomes more complex there are a variety of additional things that could go wrong (Roth et al., 2008). Products in FSC might be described as declining in value and quality throughout the supply chain after they are manufactured (Chen et al., 2020).

Products in FSCs should move downstream as efficiently as possible so that products in FSCs do not lose quality over time (Chen et al., 2020). As a result, it's critical to use IoT technology to gather, analyze, and share accurate data. To overcome these issues, diversified research into waste reduction based on IoT technology has been conducted (Brewster et al., 2017). IoT-based technologies are critical for food companies to keep track of their processes and goods at all levels (Luthra et al., 2018). By applying advanced algorithms with IoT and measuring the performance of the system according to the desired result, a system can be made that can make independent localized decisions and take appropriate actions (Misra et al., 2020). How information is transferred smoothly throughout the supply chain is crucial to improving the benefits of the entire supply chain (Yan & Huang, 2009). Food safety and quality management have become proactive thanks to the IoT, which allows food chains to be remotely monitored, regulated, planned, and optimized based on real-time data on a range of key criteria (Verdouw et al., 2016).

3.5. Classification of Internet of Things Based Technologies

In the food industry, the use of IoT-based applications to improve FSC activities has been extensively reviewed in recent years (Jagtap & Rahimifard, 2019). Artificial Intelligence, RFID, sensors/mechanisms, traceability, bio/wireless, vibrational spectroscopy, and high-pressure processing are examples of IoT-based technologies utilized in the agri-food industry (Luthra et al., 2018).

3.5.1. Radio-Frequency Identification Technology

If RFID readers are widely deployed in a supply chain, any supply chain member can exchange, query, update, or exchange information with other supply chain participants at any time (Yan & Huang, 2009). RFID offers a wide range of applications. Production process control, supply chain management, and object tracking management are among the most fascinating and successful applications (Jia et al., 2012). Inventory can be easily monitored using RFID readers placed at the entrance of the warehouse. These are crucial IoT configuration decisions in synchronizing supply chain members using products and current data to achieve a comprehensive and transparent supply chain flow. RFID can be used in containers for smart packaging technology to monitor and identify product quality during storage and transportation (Alam et al., 2021). Barcodes and RFID are among the leading technologies in the food packaging industry (Han, 2014). Because the two most important elements impacting food quality are storage time and temperature, RFID devices with a sensor interface could be critical in this industry (Dobrucka & Przekop, 2019). RFID tags, when integrated into a simple Critical Temperature Indicator (CTI), provide additional information on the precise point in the supply chain when the necessary temperature for food storage conditions is surpassed in distribution or storage (Lorite et al., 2017). A pH sensor embedded in a passive RFID tag can identify possible cold chain interruptions that will cause food spoilage (Vanderroost et al., 2014). For example, Cappai, Rubiu, and Pinna (2018) suggested an integrated animal and other product identification system for fresh meat traceability based on RFID technology and molecular analysis (DNA).

3.5.2. Vibrational Spectroscopy

Vibratory spectroscopy, which is widely preferred by food businesses, is very practical for evaluating both food quality and food specificity (Luthra et al., 2018). Spectroscopic methods help to obtain information about the protein structure of foods. Portable spectroscopy, such as Infrared (IR), Raman, and Nuclear Magnetic Resonance (NMR), allows for non-destructive, fast, and on-site study of food components and food safety analysis (Yu et al., 2020). IR spectroscopy is a faster, less expensive, and more sensitive method of monitoring and characterizing the food matrix that does not necessitate the use of a qualified analyst to monitor light absorption and reflection (Loudiyi et al., 2020). Raman spectroscopy is a useful tool for investigating protein structure in solid or liquid food systems, based on discrete vibrational transitions that occur in the fundamental electronic state of molecules (Herrero, 2008). NMR is a versatile spectroscopic technology that can be used to categorize dairy products and meat and monitor chemical changes throughout processing (Loudiyi et al., 2020). An advantage of these portable spectroscopes is their ability to non-destructively evaluate food samples by packaging; this can greatly reduce the cost of detection for food traceability systems (Yu et al., 2020). For instance, Correia et al., used miniaturized infrared spectroscopy to evaluate the quality of coffee contained in a glass bottle (2018). Environmental factors such as temperature, humidity, or food composition can affect these measurements (Yu et al., 2020). In the light of this view, the vibratory spectroscopy method is integrated with IoT, it can monitor the quality of products in real-time and provide data. In this way, it is possible to analyze and take an action with instant and precise information.

3.5.3. Bio/Wireless and Sensor/Mechanism

The quality of most foods is impaired by mass transfer phenomena such as unwanted odor absorption, oxygen invasion, moisture absorption, loss of taste, and migration of packaging components to food (Debeaufort & Voilley, 2009). Sensors can turn a physical or chemical attribute into a detectable signal that offers information on the formation, location, and amount of energy or matter (Lorite et al., 2017). For instance, sensors are used to determine the dynamic qualities of physical objects, such as CO2, ammonia, light, humidity, temperature, and pH levels. While actuators; food processing, aquaculture control systems, climate control, tractor tools, irrigation, coolers, lights and were utilized to control items such as machines remotely (Verdouw et al., 2016). Throughout the preparation and delivery of perishable foods, temperature variations are unavoidable. Temperature sensors for cold chain monitoring are common practice in food safety and quality management systems (Verdouw et al., 2016). For instance, the role of sensors in the “smart packaging” system (also described as intelligent packaging) in integrating them into food packages as labels are of great importance. Smart Packaging is used to facilitate decision-making about food availability, extend shelf life, improve food safety and quality, provide information about food, and warn about potential problems (Yam et al., 2005). Sensors or indicators can detect and inform the state of a food’s quality, such as freshness, maturity, leakage, microbial pathogens, and emitted gases, in relation to the safety of the food consumed (Alam et al., 2021). Freshness sensors, which monitor the interior and exterior of the packaging, communicate with the indicators on the packaging, allowing consumers to make informed decisions about the product’s quality (Kuswandi et al., 2011).

Smart packaging consists of components such as Time-Temperature Indicators or in short TTIs, maturity indicators, chemical sensors, biosensors, and RFID (Kuswandi et al., 2011). Critical Temperature Indicators (CTI), Critical Temperature/Time Integrators (CTTI), and Time Temperature Integrators or Indicators (TTIs) are three types of TTIs (Taoukis & Labuza, 2003). While exposure above or below a reference temperature is shown by CTIs, CTTIs show reactions at detectable rates above the critical temperature. CTTIs are handy for highlighting distortions in the distribution chain (Pavelkova, 2013). Divided into multiple categories based on the principles of color change, including biological TTI, physical TTI, chemical TTI, and other emerging types of TTIs, TTIs are devices that record the temperature history of perishable products and indicate the remaining shelf life during storage, distribution, and consumption (Wang et al., 2015). Although TTIs are tiny labels that use visual responses to monitor and record the temperature accumulation effects of a product, the critical temperature range is quite limited (Lorite et al., 2017). When using TTIs in smart packaging, the consumer can easily access the quality status of the food by looking at the color changes on the package and checking for spoilage. Physical, chemical, and biological interactions cause TTIs to change color (Mijanur et al., 2018). TTIs are useful tools for monitoring the cold chain, and despite the numerous advantages it brings to food manufacturers, retailers, and consumers, consumer acceptance of TTI technology has yet to occur (Pennanen et al., 2015). TTIs have several advantages over other devices, including their small size, inexpensiveness, and simplicity of use (Mijanur et al., 2018). TTIs have been tested on a wide range of refrigerated items throughout the cold chain, including fish and shellfish, milk and dairy products, fruits and vegetables, mushrooms, and meat products (Pennanen et al., 2015). In addition, the environmental impact caused by food waste and food waste can be reduced by using smart tags (Pennanen et al., 2015).

Data handling and transmission are also integral to the overall system. Unlike traditional packaging, intelligent packaging, with sensor technology that can detect changes that affect the quality of food's health and environmental conditions, provides real-time monitoring until the product is delivered to the customer (Alam et al., 2021).

However, some smart packaging systems transfer sensor data to an external source for real-time data processing and analysis (Alam et al., 2021). Smart packaging enables the carrying out of intelligent functions such as tracing and sensing, as well as recording and transferring specific sorts of data (Realini & Marcos, 2014). The use of freshness sensors and smart packaging systems varies greatly depending on the type and physiology of the fruit (Alam et al., 2021). Freshness sensors are divided into direct and indirect. A direct sensor detects a specific analyte directly from the fruit, while the indirect sensor relies on indirect or reactive detection of fruit spoilage due to certain freshness parameters such as temperature and/or time (Alam et al., 2021). Biosensors to detect the gas presence, freshness, temperature, and bacteria have all been developed for food goods, even though there are a wide variety of indicators (Yu et al., 2020). Smart packaging has been widely applied in the food industry and successfully commercialized (Yu et al., 2020). In the coming years, nanotechnologies, smart materials, and thin-film electronics will be integrated into packaging, making a significant contribution to future sensor technology (Schaefer & Cheung, 2018). Furthermore, the value of the global smart packaging market is estimated to be 26.7$ billion in 2024 (Alam et al., 2021; Schaefer & Cheung, 2018).

“Active packaging” takes smart packaging technology one step further. Active packaging focuses on preserving or improving the current conditions of food by designing food-compatible packaging materials like antioxidants and antibacterial additives on packaging materials (Lorite et al., 2017). The difference between active packaging and smart packaging is that active packaging provides a continuous method of quality management using active components for each individually packaged product. Through the regulating components (sensors) embedded in the packaging material, the packaging itself can release (such as moisture, ethylene, carbon dioxide, odor, or oxygen) or absorb the necessary substances (such as ethylene, antimicrobial compounds, antioxidants, flavors, carbon dioxide) and adjust the internal atmosphere conditions to respond to the needs of the packaged product (Alam et al., 2021; Yildirim et al., 2018). With the incorporation of new electronics, cloud data solutions, and wireless connectivity, packaging systems have become smarter (Chen et al., 2020).

Along with the ever-evolving technology, the use of smart packaging in the packaging of fresh products allows the protection of consumer health and safety, the improvement of the quality of the product and the prolongation of the shelf life, and the increase in the potential of reducing food waste primarily. Lorite et al., 2017 developed a microfluidic-critical temperature indicator (CTI) smart sensor prototype that remotely detects solvent melting when a critical temperature is reached, successfully integrating this sensor into an RFID tag to monitor the supply chain.

3.5.4. Artificial Intelligence

Artificial Intelligence is a game-changing field for humanity that first emerged in the 1950s. AI is the development of theories and computer systems that can carry out typical human intelligence functions such as sensory perception and decision making (Misra et al., 2020). AI can relate to human functions such as speaking and listening, reading, and writing, seeing, and analyzing, and even interacting with the environment (Camarena, 2020). AI algorithms and approaches can analyze and produce value from massive volumes of data collected by IoT devices (Mohamed, 2020). AI is used in agricultural health management, farming automation, and the establishment of demand-driven supply networks (Camarena, 2020). Load planning and route planning, which are of great importance in the distribution process of perishable food products, have high computational complexity. Different AI techniques are effective to overcome these problems (Lu & Wang, 2016). The utilization of IoT is substantially improved by increasing the adoption of AI, which provides superior data analytics possibilities (Kankanhalli et al., 2019).

3.5.5. High-Pressure Processing

High-Pressure Processing, or in short HPP, is not a new food production method, but it has yet to be broadly used in the food sector. HPP is a form of cold pasteurization procedure that is critical for food quality improvement. HPP is the non-thermal processing technology with the highest commercial success (Farkas, 2016). Since HPP is done at room temperature, it consumes less energy than standard heat treatment and is considered an environmentally friendly processing technology, as it reduces the amount of energy used for heating and cooling (Huang et al., 2017). During or before packing, products are subjected to intense pressure exerted on the food in this procedure (Luthra et al., 2018). Temperature, pressure, and exposure time are the three parameters that define the high-pressure process (Naik et al., 2013). Furthermore, it is packed as food and does not come into direct touch with processing equipment, preventing subsequent contamination of food following pasteurization (Huang et al., 2017). Hite, 1899 wrote one of the first scientific publications on HPP uses for food, prolonging the shelf life of milk. At room temperature, HPP kills food germs and extends the shelf life of the cold-chain products (Huang et al., 2017). HPP technology can enable substantial retention of sensory and nutritional qualities of food products because the treatment can be performed near ambient temperature while ensuring safety and stability during cold storage (Devi et al., 2013). Moreover, HPP is commonly used in the packaging of dairy goods, seafoods, vegetables, fruits, and meats. The global HPP market's yearly output value has surpassed $10 billion (Huang et al., 2017). Furthermore, plastic packaging materials are the best choice for HPP packaging because they can endure high pressures, are flexible, have sealing capabilities, and can prevent quality degradation during pressure application (Naik et al., 2013). HPP can be a complementary method to reduce food losses in IoT applications. It can serve as a data source on various food compositions and food structures to the database that the IoT application creates for comparison, or analysis.

3.5.6. Food Traceability

The most significant distinction between other supply chains and the FSCs is the continuous alteration in the attribute of the food from the origin to the point of consumption (Apaiah et al., 2005). During storage and transportation in the FSC, fresh and perishable foods are the weakest part of both quality and safety assurance systems, as they can be easily affected by temperatures or bad weather conditions. In order to prevent such problems, food products must be followed throughout the supply chain (Kayikci et al., 2020). In the agri-food sector, food traceability is becoming an important differentiator and is therefore mandatory for organizations (Saberi et al., 2019).

The purpose of food traceability is to ensure that the life chain of food can be traced from the very beginning to the end (Luthra et al., 2018). According to FAO and its "Food Traceability Guidance", food traceability is "the ability to discern, identify and follow the movement of a food or substance intended to be or expected to be incorporated into a food, through all stages of production, processing, and distribution" (FAO, 2017). The smart food traceability system enables the status of food ingredients to be tracked while sharing the location of the products with the user in real-time at any stage of the supply chain (Yu et al., 2020). Furthermore, traceability refers to a major effort aimed at ensuring a continuous exchange of data and a complete flow of information between all relevant actors and stakeholders of the food chain (Mania et al., 2018).

It is crucial that all FSC stakeholders have access to a central and strong traceability system that connects data (Galvez et al., 2018). Information provenance and traceability are crucial in the food sector in improving food quality and safety (Saberi et al., 2019). Before the advent of new-age technology such as IoT, food inventory tracking was commonly have done manually in homes and small restaurants or with the POS (Scale Point) machine used in restaurants or supermarkets (Narayan et al., 2018). In order to complete the distribution process without any FLW throughout the food supply, users can follow by connecting objects such as trucks and storage coolers to relevant equipment via the internet, what types of food they currently contain and how these foods respond to relevant environmental conditions such as light, humidity, temperature and shock or location (Kayikci et al., 2020).

The mostly IoT approach involves using networked technology to achieve specific production targets and support sustainable agriculture in the process by ensuring transparency through the entire supply chain. The IoT enables advanced solutions to track and trace remote shipments and products during the supply chain process (Yu et al., 2020; Sundmaeker et al., 2016). Furthermore, Wi-Fi, GSM, LTE, Bluetooth, there are such technologies developed for specifical usage for IoT. Dash 7 Alliance Protocol 1.0, LoRaWAN, RPMA, IEEE P802.11ah, nWave (Quinnel, 2015; Borgia, 2014). These devices in logistics are mounted on trucks, packages, household equipment or inside flat food packaging (Bogataj et al., 2017; Jie et al., 2015).

Reducing the agri-food product losses and waste and getting high efficiency from the agri-food product distribution process with the application of IoT. The application of IoT has a significant impact on reducing food wastage (Sundmaeker et al., 2010). Including more sophisticated traceability in the existing FSC will reduce FLW while ensuring food safety. Thus, the agricultural supply chain that is matched with IoT is a crucial improvement trend in the future. Nevertheless, there is still a lack of research on the improvements made to reduce agricultural FLW in Turkey and the application of IoT technology in addition to these improvements. The IoT is a network of digital-physical objects that provides agility, visibility, monitoring, and information sharing to facilitate real-time planning, control, and coordination within the company and among other links in the supply chain (Ben-Daya et al., 2019).

The supply chain model of agri-food products under the IoT area is growing up with the rapid improvement of the IoT (Xuemei, 2015). The IoT enables to build strong integration between stakeholders and farmers in the FSC with the collection of necessary data. An essential part of agri-food production, reducing FLW will reduce the need for increasing production (SETA, 2019). The IoT is a tool that monitors, controls, plans, and optimizes the supply chain process remotely and in the real-time status of products through the internet. The IoT will make a comprehensive contribution to supply chain management in the future (Tu, 2018).

3.6. Actions Taken to Reduce Food Loss and Waste in Developing Countries

Food waste management may change from nation to country and at each stage of the supply chain, depending on the approach used and the type of food (plant or animal source) (Scherhaufer et al., 2018). For developing countries, the priority is raising the education level of farmers, building up the developed infrastructure with public or private investments, and the most important one is supporting the people for better technology usage. In addition, agri-food products fall into the perishable food category. In order to manage the perishable food process effectively, it needs to ensure being accurate, timely, accessible, and reliable data (Fernandes et al., 2013). How to collect and store data throughout the supply chain flow of agri-food products, then how to process and analyze this information, and how to visualize the analyzed information is a vital issue that requires serious research (Chen et al., 2019). Management of data information ensures traceability and smart management of the agri-food products supply chain. In developing countries, both the private and public sectors have an important role to play in improving FSCs. Infrastructure, transportation, food, and packaging sectors are all areas where these countries must invest, while at the same time supporting small producers or farmers and encouraging them to diversify and grow their production and marketing (Gustavsson et al., 2011).

The research might focus on the significantly more retail stage in developing countries, based on the current studies (Koester, 2014). It would be interesting to examine how new smart information and automation capabilities affect perishable supply chain performance, such as lowering fresh product PHL (Wu et al., 2016). The aim of this thesis is to close this gap in the literature. For this purpose, the IoT technology will be reviewed in Turkey to analyze the dimensions and the present findings for the determination of the agricultural supply chain stages where the waste is intense in order to prevent and reduce FLW.

CHAPTER 4
FIELD STUDY (SURVEY) FOR THE ANALYSIS OF THE INTERNET OF THINGS APPLICATION OF AGRICULTURAL FOOD SUPPLY CHAIN IN TURKEY

4.1. Research Methodology

Uncovering a fact or solving a problem is possible by doing research. A systematic examination or inquiry in which relevant data is gathered, evaluated, and interpreted in many ways to explain or describe a phenomenon has been defined as research (Mackenzie & Knipe, 2006). Researchers can use a variety of research methodologies to carry out their studies, depending on the research topic and type. “Quantitative”, “Qualitative” and “Mixed Research Methodologies” are the most preferred methods. In general, when answering research questions that require numerical data, a quantitative technique is favored, while a qualitative approach is used for questions that require textual data, and a mixed-method approach is used for questions that require both numerical and textual data (Williams, 2007). The quantitative research approach, which is commonly employed in natural sciences such as physics, chemistry, and biology, focuses on measurable occurrences and numerically expresses observed phenomena during analysis. The qualitative research approach, which is commonly employed in the field of social sciences (sociology, psychology, etc.), is used to reveal facts and occurrences in a natural environment in a realistic way. While closed-ended questions, instruments, pre-determined hypotheses, etc., are used in quantitative research methods, in qualitative research approach, interviews, open-ended questions, processes determined by the participant, etc., are used data collection methods are used. The mixed methods research, or in short MMR approach is a type of study that combines quantitative and qualitative research techniques or procedures in a single study to gather and analyze the data (Johnson & Onwuegbuzie, 2004; Cresswell, 2003). Jick first proposed this strategy in 1979 as a way to bring qualitative and quantitative methodologies in social science research closer together (Creswell et al., 2003). MMR is particularly suited to areas of the social sciences that attempt to create results that can be used for interventions and policy more or less directly (Strijker et al., 2020). Another feature of MMR is that it is a comprehensive and creative form of research that allows the use of multiple approaches without limiting the researchers' choices, taking advantage of the strengths of both methods (Johnson & Onwuegbuzie, 2004). In other words, in researches in which an MMR is used, numerical data specific to quantitative research and narrative data specific to qualitative research method is used simultaneously on the research problem. In research, a more effective and detailed interpretation can be made by using the combination of these two different methods.

In this research, in order to prevent or reduce FLW throughout the FSC, corporate companies that produce and export rapidly perishable agri-food products in Turkey, how widely IoT technology is used today, and how positively they approach the application of IoT technology in company operations in their future investments, are analyzed by using a mixed research method combining quantitative and qualitative methods was used to further analyze numerically and textually. In light of this view, a questionnaire was created using the MMR approach. Yes/No Questions, Open-Ended Questions, and 5-point Likert Scale Questions were given to the participants for survey application in order to analyze the thesis in a comprehensive way.

In this regard, there are four research questions to which this academic research seeks answers:

RQ1: What impact does the use of Internet of Things have on the minds of managers in agricultural food product supply?

RQ2: Why do food loss and waste occur during the supply of agricultural food products?

RQ3: What are the effects of technological applications in agricultural food products trade in Turkey on minimizing food loss and waste?

Consisting of a 20-question questionnaire, this research was divided into three parts in order to get effective answers to the questions: Yes/No Questions, Open-Ended Questions, and 5-point Likert Scale Questions. The questions were designed considering the relevance of IoT applications in reducing FLW in the agricultural FSC. While the Yes/No Questions were related to the information and attitudes of the people about the research subject, they were also supported with Open-Ended Questions, which were asked to give detailed information or examples according to the answer given in order to analyze the subject in more detail. Open-Ended Questions, which the participants feel freer to express while answering, aim to provide detailed comments and information about the question. Therefore, while answering the relevant question, it allows the participants to make more detailed explanations about the subject and give examples. The 5-point Likert Scale Questions are important to analyze the participants' level of awareness about the contributions of IoT and what are the company motivations or barriers in using IoT applications to reduce FLW in operational processes. Questions in a 5-point Likert Scale make a great contribution to numerical representations in the survey analysis part. In this regard, such questions are important in understanding the importance of applying IoT technology when improving these processes and at which supply chain stage companies experience FLW due to which parameters. In order to reduce or prevent the amount of FLW during the FSC process of rapidly deteriorating agri-food products, it is aimed to find an answer to understand how much corporate companies benefit from IoT applications on an operational basis in the current order and their willingness to invest in this technology in the coming years. Therefore, at the beginning of the questionnaire, the participants were informed about the subject and purpose of the academic study. Each question is classified into the three categories mentioned at the beginning. With this classification, it provides convenience to the participants while answering the questions, and also contributes to the easier analysis of the survey results for the researcher.

4.1.1. Data Collection and Analysis

The demographics of this survey consist of five different corporate companies that produce perishable agri-food products in Turkey and export them abroad. All of the companies participating in the survey fall into the category of companies exporting animals and animal products. While four of the companies export chicken and eggs, only one of the companies produces and exports milk and dairy products. The company information of the survey participants is as follows: Pınar Entegre Et ve Un Sanayi Anonim Şirketi, Sütaş Süt ve Süt Ürünleri Anonim Şirketi, Güres Tavukçuluk Üretim Pazarlama ve Ticaret Anonim Şirketi, Yiva Zeytin ve Zeytinyağı Sanayi Ticaret Anonim Şirketi, Abalıoğlu Lezita Gıda Sanayi Anonim Şirketi. Such companies have been chosen because corporate companies producing agri-food products have the opportunity to invest in technology applications throughout the FSC and work with employees with this knowledge. In this study, the gender and age of the participants were ignored in the analysis. Due to pandemic conditions, questions were sent online to company employees of companies producing and exporting perishable agri-food products (fresh fruit and vegetables, milk and dairy products, animal and animal products, etc.) along the supply chain and then collected. The survey was conducted between September and October 2021. At the start of the survey, a brief description of the survey's aim, scope, and how to answer the questions is given, and the questions are divided into three parts (Yes/No Questions, Open-Ended Questions, and 5-point Likert Scale Questions) to make it easier for participants to answer and the researcher to analyze the responses. The first eleven questions were asked as Yes/No Questions. Although it differs from question to question, in order to better analyze the subject, the participants were generally asked to detail their answers and give examples according to their answers. In the continuation of the questionnaire, questions twelve, thirteen, and fourteen were asked Open-Ended. From the fifteenth to the last question, the first part of each question was asked Open-Ended type, while the second part of the questions was asked with a 5-point Likert Scale question type related to the first part. In this section, the participants were asked to classify the questions asked from 1 to 5. Response alternatives represent respectively: 1 (Very Poor), 2 (Poor), 3 (Fair), 4 (Good), and 5 (Excellent). The survey questions are listed in the analysis of each question below (a detailed copy of the survey study may be accessed in Appendix 1-Survey):

Question 1:

The survey first begins by asking respondents to describe the production area of the company they work for. Fresh fruit and vegetable producer/exporter, milk and dairy product producer/exporter, livestock and livestock product producer/exporter (i.e., meet, eggs, chickens) and other alternatives are available.

The answers given in this direction are as follows: 1 milk and dairy product producer/exporter which is Sütaş Süt ve Süt Ürünleri A.Ş. and 4 livestock and livestock product producer/exporter which are Pınar Entegre Et ve Un San. A.Ş., Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş., Abalıoğlu Lezita Gıda San. A.Ş., Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş. Pınar Entegre Et ve Un San. A.Ş. produces meat and meat derivatives, while the other three companies produce eggs and chickens.

Question 2:

The second question asks whether companies experience FLW when sourcing perishable products. If participants answer “Yes”, they are asked to explain at what stages of the supply process, how often, and how much food is wasted or lost. In this question, the ratio of “Yes” (80%) and “Undecided” (20%) answers. The participant from Pınar Entegre Et ve Un San. A.Ş. answered the question as “Undecided”. The detailed answers of the participants who answered “Yes” are as follows:

- Products with expired shelf life, products with damaged packaging during supply, products that deteriorate due to high temperatures during storage, and transportation to sales points due to technical failures can be given as examples (Sütaş Süt ve Süt Ürünleri A.Ş.).
- FLW can occur during live chicken production. Every part of the anatomical structure that emerges during the processing of chickens and is not suitable for human consumption can be called FLW. In addition, stale eggs or damaged eggs that are not suitable for human consumption are also considered in the FLW category (Abalıoğlu Lezita Gıda San. A.Ş.).
- Examples of FLWs our company has experienced are eggs that are broken or damaged during the supply chain, or spoiled eggs that are not suitable for consumption due to storage conditions, eggs that are not offered for sale because they do not meet consumer quality standards or eggs from sick broilers (Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş.).
- Table eggs constitute 99% of our exports. Since the product supplied is sensitive and the transit time is a minimum of 17 days, breakage and damage may occur during transportation (Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş.).

Question 3:

The third question aims to measure whether companies are environmentally conscious about FLW. In this question, all participants stated that their companies are sensitive to the environment in terms of FLW answering “Yes”. Participants from Pınar Entegre Et ve Un San. A.Ş. and Sütaş Süt ve Süt Ürünleri A.Ş. explained in detail what kind of activities their companies carry out in order to be sustainable and sensitive to the environment. The detailed answers are as below:

- The participant from Pınar Entegre Et ve Un San. A.Ş. expressed that Pınar Et is doing its best to be a company that produces sustainable environmentally sensitive projects. For example, we have reduced the number of packaging materials such as paper, and plastic we use with our optimization efforts. This work has reduced both our harmful carbon emissions and the number of trees cut down for packaging production. Pınar Et also work on energy and water saving. In 2019, it reduced its water footprint by 8.6%. In addition, it also raises awareness of the employees on this issue, thanks to the training given periodically about being sensitive to the environment.
- The participant from Sütaş Süt ve Süt Ürünleri A.Ş. stated that As Sütaş, we carry out studies for energy and resource efficiency. The electricity used in our production facilities is realized with the renewable energy we obtain from organic waste and fertilizers in the farms. As part of the "Zero Waste Project", we recycle nearly all of our waste generated during the process. We try to minimize our use of packaging materials. In order to reduce carbon emissions, we carry out optimal route studies during the supply. In addition, in order to be sensitive to the environment, training is given to our company employees and producers to raise awareness.

Question 4:

Forth question asks whether companies reuse FLW generated during the procurement process. To illustrate agricultural FLW for reuse, examples of use in agriculture as fertilizer or recycling such as organic feed are given. If the participants answered "Yes", they were asked to give examples of how and in which areas they recycle these losses and wastes. In this question, the ratio of "Yes" (80%) and "Undecided" (20%) answers. Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş. answered as "Undecided" while Pınar Entegre Et ve Un San. A.Ş., Sütaş Süt ve Süt Ürünleri A.Ş., Abalıoğlu Lezita Gıda San. A.Ş., and Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş. answered as "Yes". There are some important answers from the participants, who answered the question as "Yes". The detailed answers are given below:

- Animal waste or returned products are recycled by using them in the production of feeds used in animal husbandry. Also, the fertilizers produced in poultry production are evaluated at the manure processing plant in Ören, Balıkesir (Pınar Entegre Et ve Un San. A.Ş.).

- Sütaş Süt ve Süt Ürünleri A.Ş. products that have expired, organic waste from farms and even animal manure waste from livestock facilities is sent to ENFAŞ Enerji Elektrik Üretim A.Ş., a subsidiary of Sütaş Süt ve Süt Ürünleri A.Ş. to be converted into biogas. ENFAŞ currently has three biogas power plants located in Aksaray in Central Anatolia, Karacabey in the Marmara Region, and Tire in the Aegean Region. Electricity, steam, and hot water produced at ENFAŞ, one of the largest biogas production facilities in Turkey, are used for regeneration at Sütaş facilities (Sütaş Süt ve Süt Ürünleri A.Ş.).
- In Lezita, no part of the chicken that you can think of in its anatomical structure becomes a worthless waste. Any part of the chicken that is not suitable for human health is not directly placed on the market. This resulting FLW are processed by rework or rendering method as a last resort, creating a new value as a raw material for fish feed and being offered for use again. Abalıoğlu Gıda San. Tic. owns the Lezita Fish company within its structure and the fish feed raw material obtained from this company is used in the activities of this company (Abalıoğlu Lezita Gıda San. A.Ş.).
- In our facility, FLW are re-evaluated as the damaged eggs are liquefied and re-evaluated in the pasteurized facility, and the fertilizers produced during production are burned to contribute to energy production (Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş.).

Question 5:

The fifth question is aimed to find out whether the companies carry out the storage and transportation stages of the supply chain within their own company, without purchasing services from a third-party company. If the participants answered “Yes”, the companies were asked to explain what kind of technological applications they use to ensure food safety in product supply. If the answer is “No”, they were asked to explain what features they pay attention to have in the process of deciding to work with companies while receiving services from third-party companies. In this question, the ratio of “Yes” (20%) and “No” (80%) answers. Sütaş Süt ve Süt Ürünleri A.Ş. answered the fifth question as “Yes” while the other companies answered as “No”. There are some important answers from the participants, who answered the question as “No”. The detailed answers are given below:

- Pınar Et distribution activities are carried out with Yaşar Entegre Pazarlama (YBP), one of the Yaşar Group companies, which has the largest state-of-the-art cold and frozen product distribution chain network spread throughout Turkey. YBP maintains its operations with the most up-to-date software systems and shares the analysis results with Pınar Et in real-time. Thanks to the advantage of being in the same company family and the wide technological distribution network it offers, YBP plays an important role in our distribution activities while our products reach 150 thousand sales points safely every day (Pınar Entegre Et ve Un San. A.Ş.).
- Güres pays attention to the references of the companies, service quality, customer services, and support, cost-effectiveness, equipment, and transportation vehicle quotas to meet our demand (Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş.).
- Lezita does not have its own fleet. We make agreements with logistics companies that have technological competence, sectoral knowledge, and experience that will not break the chain in cold chain transportation. As livestock transportation and cold chain transportation is a very sensitive issue, we attach importance to the fact that the companies we work with have experience in this subject. In this context, we do not leave anything to chance as a company since any disruption is very critical for the health of living things in the first place. We prefer to work with companies that offer the opportunity to follow the process transparently at all stages, are suitable on a price basis, and have high vehicle capacity flexibility (Abalıoğlu Lezita Gıda San. A.Ş.).
- Yiva prefers to work with solution-oriented third-party companies that offer opportunities to monitor and inspect the status of our products in real-time during transportation, are technologically competent, and can safely deliver our products to the destination without breaking the cold chain (Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş.).
- Sütaş has a fleet of 1550 vehicles. This fleet supplies products to 150 thousand points of sale every day without breaking the quality chain. We constantly monitor the cold supply chain by monitoring the heat of our vehicles and satellite. In addition, we inspect whether the vehicle cargo doors are opened only at the delivery points (Sütaş Süt ve Süt Ürünleri A.Ş.).

Question 6 & 7:

In the sixth question, it was first given the information that environmental sensors are used to monitor parameters such as humidity, temperature, and CO2 in real-time in the supply chain to reduce FLW. Based on this information, it was measured whether companies use such sensing technologies to monitor food quality in the FSC. If companies benefit from such technologies, they were asked to give examples of the technological applications they use. In this question, all participants answered as "Yes", stating that their companies use such sensing technologies to monitor food quality in the FSC. The detailed answers given by the companies about the detection technologies they use are as follows:

- While technological warehouses with heat control systems are used in the storage process at Pınar Et facility, products are specially packaged with smart packaging technologies before they are distributed to ensure food quality for a long time. It is an important criterion for the factory that this subject, which falls under the field of product quality and assurance, is inspected by quality assurance shift engineers within the factory, and if certain problems are encountered, it is not evaluated in the category of products to be blocked and sold (Pınar Entegre Et ve Un San. A.Ş.).
- Raw milk collected from cows must be shipped to Sütaş facilities for processing within two hours at the latest. For the safety of milk, it must be transported and stored at certain temperatures. Thermocouple heat meters that control milk storage temperatures and level sensors that measure humidity level are used. There are high precision air separators in the milk transport tanks in our fleet. In addition, we use Therm Aseptic VTIS unit during the heating phase of milk in our factory. Compared to other heating systems, this heating system reduces product loss by 40% and production cost by 15% during the process. We also produce by-products such as yoghurt, buttermilk, butter, and cheese from milk. In the production tank of such by-products, sensors measure temperature, pH, and pressure (Sütaş Süt ve Süt Ürünleri A.Ş.).
- Humidity, temperature, CO2, ammonia sensors, metal detectors, and smart IRIS cameras that distinguish product quality are used in our company to monitor food quality. Temperature and humidity sensors are generally used in the storage process. To perform stock control in an integrated manner, RFID

handheld terminals and business intelligence programs work in conjunction with each other. The entire production and shipping area is controlled by cameras in real-time. There are alarm sensors in the bands and machines on the production line that inform in cases such as product jams. While metal detectors are used in the entire production line, special stretching machines are used in the shipping area to keep the food quality in suitable conditions for a long time (Abalıoğlu Lezita Gıda San. A.Ş.).

- By placing a heat meter thermometer on the containers or vehicles that are loaded, we monitor the temperature and humidity of the environment during transportation in a transparent way, and we check the analysis on a graphic basis. In addition, technologies such as RFID and smart packaging are also used in our company (Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş.).
- It is supplied in refrigerated containers where suitable conditions are provided during the transportation of the products. Analog temperature recording devices are placed in the container to monitor the temperature-humidity changes in the container transparently during transit. When the shipping process of this device is finished, the graphic inside the device is removed and the temperature record is easily seen (Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş.).

In response to the sixth question, in the seventh question, companies using such sensing technologies were specifically asked whether they use smart packaging consisting of sensors and indicators to delay or prevent food spoilage. In this question, the ratio of “Yes” (80%) and “No” (20%) answers. Pınar Entegre Et ve Un San. A.Ş., Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş., Sütaş Süt ve Süt Ürünleri A.Ş., Abalıoğlu Lezita Gıda San. A.Ş. answered “Yes” that they use smart packaging in their processes while Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş. replied “No”, that is, they do not use smart packaging technology.

Question 8:

The aim of the eighth question is to measure whether they have heard of the term “Internet of Things”, which enables smart digital devices to communicate with each other over the internet and take real-time action. In this question, the ratio of “Yes” (60%) and “No” (20%) and “Undecided” (20%) answers. Pınar Entegre Et ve Un San. A.Ş., Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş., and Abalıoğlu Lezita Gıda San. A.Ş. answered as “Yes” while Sütaş Süt ve Süt Ürünleri A.Ş. answered “No” and

Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş. answered as “Undecided”.

Question 9:

In the ninth question, it was measured whether companies benefited from IoT technology such as smart transportation, smart storage, smart packaging throughout the perishable food supply process. If the answer is “Yes”, they were asked to explain at what stage of the supply chain process they use such IoT technologies. In this question, the ratio of “Yes” (60%) and “No” (40%). Sütaş Süt ve Süt Ürünleri A.Ş. and Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş. answered as “No”. The detailed answer of the companies that answered as “Yes” is as follows:

- The participant from Pınar Entegre Et ve Un San. A.Ş. expressed that there are temperature sensors in every vehicle in order to maintain the cold chain. These sensors give real-time notifications when the vehicle’s cover is opened, or heat loss occurs, and the necessary action is taken.
- The participant from Abalıoğlu Lezita Gıda San. A.Ş. mentioned that in Lezita, real-time tracking and monitoring of shipped products is carried out, and various technologies are used to control food quality during production and cold storage stages.
- The participant from Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş. expressed that with the barcode recognition system, stock tracking and loading tracking are carried out.

Question 10:

The tenth question focused on whether there are qualified personnel skilled in the use of IoT technology. In this question, the ratio of “Yes” (60%) and “No” (20%) and “Undecided” (20%) answers. Pınar Entegre Et ve Un San. A.Ş., Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş. and Abalıoğlu Lezita Gıda San. A.Ş. answered as “Yes” while Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş. answered as “No” and Sütaş Süt ve Süt Ürünleri A.Ş. answered as “Undecided”.

Question 11:

In the eleventh question, respondents were asked whether they think the companies’ current infrastructure is sufficient to use IoT technology to invest in IoT technology in the future. If the participants answered “No”, they were asked to explain what they wanted to improve their company infrastructure to use IoT technology. In this question, the ratio of “Yes” (40%) and “No” (40%) and “Undecided” (20%). Pınar Entegre Et ve Un San. A.Ş. and Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş. answered as “Yes” while Sütaş Süt ve Süt Ürünleri A.Ş. answered as “Undecided”. Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş. and Abalıoğlu Lezita Gıda San. A.Ş. answered as “No”. The detailed answers of companies that think that their companies are not sufficient in terms of infrastructure to invest in IoT technology in the future are as follows:

- Investing in IoT technology is insufficient in terms of infrastructure based on information technology (Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş.).
- All structures in poultry integrated facilities are interconnected in terms of performance and efficiency. IoT is very important in terms of improving chain and traceability by connecting one structure to another. Unfortunately, our infrastructure is not sufficient to use these technologies in all processes of the company. Biosecurity is extremely important especially for broiler production. Animals are very sensitive to environmental conditions and in this sense, we try to use all kinds of technology to use the IoT at these stages, but it is insufficient in terms of infrastructure because it is a completely isolated, private area. In the entire poultry sector, the poultry houses are owned by small producers. This process makes it difficult to make such technological investments. In the field of production, all kinds of quality improvement and environmental conditions are of extreme importance for our company. In this sense, we continue to develop our systems by following the latest technology products (Abalıoğlu Lezita Gıda San. A.Ş.).

Question 12:

In the twelfth question, participants were asked to explain how companies produce and export products and services. For the participants to explain the processes more flexibly and easily, this question was asked as an open-ended question. To understand what kind of processes and stages perishable food products go through from production to the final stage of export, the participants were asked to give information about the production and export processes of the companies. The detailed answers are as below:

- The participant from the Pınar Entegre Et ve Un San. A.Ş. mentioned that Pınar Et has a wide product range including deli (i.e., sausage, salami, sausage, bacon), frozen meat products (i.e., burgers, meatballs, coated meat products), frozen seafood (i.e., shrimp, squid, coated seafood), unprocessed meat products (i.e., turkey, lamb, veal), frozen meat and plant-based products, and canned meat products. The company has many contracted domestic fattening farms from different regions of Turkey. Pınar Et produces food in accordance with quality and standards in its modern integrated meat processing facilities equipped with the latest technology. It exports its products to more than twenty countries. Food quality and control in production processes are carried out in well-equipped laboratories of Pınar Et. Pınar Et produces technological products in its own facility. It carries out cutting operations with methods. Distribution activities are carried out with Yaşar Entegre Pazarlama (YBP), one of the Yaşar Group companies that have Turkey's largest cold and frozen product distribution chain network.
- The participant from the Sütaş Süt ve Süt Ürünleri A.Ş. expressed that to obtain high-quality milk with high nutritional value, we feed the cows with healthy fodder plants and natural forages that we produce in our own facilities. In addition, there is an Input Quality Control Laboratory in Sütaş Dairy Production Facilities. We control the milk collected from our milk producers all over Turkey with fourteen different tests and constantly inspect the naturalness and quality of the milk we process. We transform the milk, which we process meticulously in our fully integrated facility, which complies with hygiene and quality standards, into yoghurt, ayran, cheese, and butter, and present them to the country and foreign markets for sale. We export our products to more than thirty countries.
- The participant from the Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş. described that Güres Group is the largest fully integrated egg production facility in our country, gathered under one roof, from Egg Production Facilities to Feed Factories, from Viol Factory to Hatchery, Pullet and Breeder Production Facilities, from Fertilizer Production Facility to Cage, and Equipment Production Factory. It is produced in the field of chicken eggs, pasteurized liquid eggs, quail eggs, quail meat, and chicks. Layer broiler chicks imported from Germany, France, and the Netherlands are specially raised in

fully closed breeding production houses. The chickens are fed with the feed produced in our own feed factory, and after the eggs are collected and sorted untouched by hand, they are delivered to the consumers from our production facilities in the cold chain without waiting in their health-certified hygienic packaging. Our facility produces 1.5 billion eggs per year, and we deliver to all Turkish and eight countries including the Middle East and African countries by road and sea transport in refrigerated containers.

- The participant from the Abalıoğlu Lezita Gıda San. A.Ş. expressed that Lezita, which has a wide range of products, has integrated facilities in the poultry production sector. It produces its own feed. Import broiler breeding chickens for breeding. There are breeding farms owned by the company. Here, breeding chickens are raised from day zero. The chicken sends its eggs to its hatcheries. It sends the hatched chicks to the predetermined contracted coops. Then, ready-to-eat broiler chickens grown in the hens are brought to the slaughterhouse. After slaughtering and shredding the chickens in the slaughterhouse, they are packaged for sale. At the same time, further processed chicken products (deli, coated products and doner kebabs, etc.) are produced and presented to the markets.
- The participant from the Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş. mentioned that Yiva is a company that exports table eggs and frozen chicken to Middle Eastern countries. Our products are grown in our own coops, stored under suitable conditions, and then presented to our country and foreign markets in a fresh way to be sold with cold chain transportation.

Question 13:

The purpose of the thirteenth question is to analyze which parameters play a role in the conversion of products to FLW by companies throughout the supply chain. The answers are generally gathered based on the reasons that may arise due to the breaking of the cold chain throughout the supply and that will affect the quality and safety of the food. Humidity and temperature changes that occur as a result of the breaking of the cold chain in general, and damage to the packaging (such as impact, tearing, leakage) are the leading parameters that cause the products to deteriorate. However, it is still important to examine the detailed answers given by the companies. Here are detailed examples from companies of the parameters involved in converting products to FLW throughout the supply chain:

- It is of great importance to protect the cold chain correctly during transportation to sales points. Humidity and temperature are important factors for packaging damage and spoilage of meat products (Pınar Entegre Et ve Un San. A.Ş.).
- The uncontrollable amount of heat and humidity during storage and transportation is the most effective parameters in the transformation of our wrong packaging products into FLW (Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş.).
- Keeping milk and dairy products in suitable conditions in the cold chain throughout the supply chain is a very important issue for food safety. In addition, deformed and leaking products in product packages come into contact with air and cause bacterial growth. Our milk is transported in special milk tankers carrying four separate tanks of four and a half tons each. It is important to analyze the interior of these vehicles to ensure food safety after each transport. The tools used must not be damaged or rusty (Sütaş Süt ve Süt Ürünleri A.Ş.).
- Reasons such as unsuitable temperature and humidity in storage and transportation conditions, damage to the packaging (tearing, abrasion), leakage of ammonia gas used in air cooling systems, and failure to control the carbon dioxide level in the poultry house cause the products to deteriorate. Another important parameter is that the waiting time of the broiler brought to the field by trucks for the slaughter phase exceeds 1.5 hours. If the broilers stay in the waiting areas for a long time because they do not have sweat glands, the stress level will increase due to effects such as high temperatures, resulting in negative animal welfare and even death rates may increase (Abalıoğlu Lezita Gıda San. A.Ş.).
- Due to the high-water content in chicken meat, it can easily spoil if it is not properly packaged, stored, and distributed safely. The carrying capacity of the cages loaded on the vehicles should be considered while the chickens are brought to the slaughter stage. If chickens are placed in overcapacity poultry houses, injury and crushing may occur during transport (Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş.).

Question 14:

The fourteenth question was asked to determine at which stage of the product supply chain such as production, packaging, storage, and transportation it is more beneficial for companies to use IoT technology. In answering this question, participants were asked to consider the important stages through which the food produced by their company passes through the supply chain and which stage could add more value to the company by investing in IoT technology.

- The participant from the Pınar Entegre Et ve Un San. A.Ş. and Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş. think that their use of IoT technology will benefit all supply chain stages such as production, packaging, storage, transportation.
- The participant in company Abalıoğlu Lezita Gıda San. A.Ş. also agrees with the other two companies, but specifically states that she believes that the use of IoT technology will be beneficial in the production and packaging stages, which are the most critical in Lezita's current period.
- The participant from the Sütaş Süt ve Süt Ürünleri A.Ş. believes that IoT technology will be useful for only storage and transportation process.
- The participant from the Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş. think that applying IoT technology is beneficial for packaging, storage, and transportation process.

4.1.2. Open-Ended Questions Part of 5-point Likert Scale

This part will be analyzed in two phases. The first stage covers the answers given by the participants to the Open-Ended Questions from the 15th to the 20th question. In the second stage, statistical analysis of the answers given to the questions asked as a 5-point Likert Scale type question related to the Open-Ended Questions from 15 to 20 questions will be made. In the analysis section, the answers given by the participants were presented as a frequency table according to the statistical study. Frequency tables were interpreted based on each question. The answers in this table are visualized with a pie chart to see the overall picture more clearly.

Question 15:

In question fifteen, participants were asked what the barriers to their company's use of IoT technology are. The purpose of this question is to find out what obstacles might be in front of companies if they want to invest in such technologies in the future.

- The most important reason that complicates the transition of our company to industry 4.0 technologies in an integrated manner is the live animal activities. Also, due to Lezita's product portfolio sales strategies, there is a wide variety of products with very small weight differences. In this context, applying such technologies in the production process requires advanced and comprehensive machines. In addition, although the poultry industry, as a labor-intensive sector, has good places in terms of using these technologies, it is a very complex process to completely connect and control the supply chain in integrated facilities. As a result, we are trying to improve things and use such technologies, but we have a long way to go to ensure that it is used at all stages (Abalıoğlu Lezita Gıda San. A.Ş.).
- The high costs of such technological investments and the difficulty in finding authorized personnel who can use the technology are our company barriers. We also have concerns in terms of cyber-attack and security (Sütaş Süt ve Süt Ürünleri A.Ş.).
- The high investment cost in IoT technology and the fact that we do not have qualified personnel to use such technologies in our company are among the company barriers (Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş.).
- The high cost of the technology to be invested to control all our procurement processes is among our company barriers (Pınar Entegre Et ve Un San. A.Ş.).
- As a company, we have no barriers to investing in IoT technology. Considering the benefits of IoT, we may be more willing to invest in IoT in the coming years (Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş.).

Question 16:

In the sixteenth question, companies were asked what the economic impact of FLW during the process reflected on companies. This question was asked to the respondents to gauge whether they were aware of the negative economic impact of FLW on their company.

In this question, all companies united on a common denominator and reported that the FLW experienced was a loss for their companies in terms of economy. In addition, considering the limited resource problem experienced today, they talked about the importance of using the resources we have more cautiously and reducing these losses if possible. This reduced FLW will make a positive contribution to both companies in economic terms and to nature under the name of saving in the next process.

Question 17:

In the seventeenth question, participants were asked what measures they have taken as a company to reduce their carbon footprint (activities based on carbon dioxide released into the atmosphere). The measures taken by companies to reduce their carbon footprints are as follows:

- The participant from Abalıoğlu Lezita Gıda San. A.Ş. expressed that Lezita Logistics Department works completely by optimizing all routes. Lezita also has cogeneration facilities to save energy.
- The participant from Sütaş Süt ve Süt Ürünleri A.Ş. stated that Sütaş has been attaching importance to sustainable activities to contribute to nature since 2013. We are doing our best to reduce our carbon footprint along the supply chain. For instance, in 2019, we reduced our Greenhouse gas emissions during production by almost 350 thousand tons. In this context, the equivalent of eight million trees according to statistical data. Sütaş has its own fleet of vehicles, and the Logistics Department has greatly reduced the kilometers we have covered by giving importance to route optimization studies. We are also working to reduce the packaging materials we use for packaging. In addition, Sütaş has the "Low Carbon Hero Award" for its efforts to reduce carbon emissions.
- The participant from Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş. mentioned that to reduce our carbon footprint, we minimize the use of packaging and make sure that the packaging we use is environmentally friendly and recyclable.
- The participant from Pınar Entegre Et ve Un San. A.Ş. expressed that thanks to the R&D studies of Yaşar Group carried out continuously in our company, we strive to reduce our company's carbon footprint every year. For example, our carbon emissions, which emerged during the shipment, decreased by approximately more than 1 million tons thanks to the optimized route and our efforts to ship more products with fewer vehicles, carried out with the Pınar Logistics Department. In addition, we prefer environmentally friendly engine vehicles. A total of 128 tons of CO2 emissions have been reduced in our company, together with the existing paper and plastic packaging materials optimization studies. In 2019, it reduced its carbon emissions by almost 10%.

In line with our goals, we have such studies for the coming years. Furthermore, Pınar Et is a member of the Carbon Disclosure Project (CDP), which measures companies' environmental performance and strategies.

- The participant from Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş. stated that for the sake of efficient resource use, Güres, which provides some of the energy it uses in production from solar energy, has managed to reduce its carbon footprint to some extent. Güres pays attention to the use of chimneys with special filters to reduce carbon emissions. In addition, the fertilizers produced during chicken production are processed at Güres Fertilizer Processing Facilities and offered for sale to be reused in agriculture. Moreover, another usage area of manure is created by burning at the Güres Energy power plant. In this way, electricity is produced from manure.

Question 18:

The purpose of the eighteenth question is to find out what reasons will motivate companies to invest in IoT implementation in the future. The detailed answers given by each company are as follows:

- The participant from Abalıoğlu Lezita Gıda San. A.Ş. thinks that reducing FLW in production, transparent traceability, and traceability of the systems throughout the process, and the benefit of making food waste more valuable increase our motivation.
- The participant from Sütaş Süt ve Süt Ürünleri A.Ş. expressed that being able to monitor the temperature conditions in real-time and transparently during cold chain transportation thanks to IoT technology, or instantly informing authorized persons of any temperature change thanks to the IoT system and taking action without wasting time is an important motivation for us. n this way, we can have a more integrated system for food safety. In addition, using IoT technology can help us manage our fleet in a more integrated way.
- The participant from Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş. mentined that I think that IoT investments will make a positive contribution to our company to analyze at what stages and for what reason damage and loss occur during the supply of our eggs to distant countries. It is a motivation for us that the system informs us or intervenes in any technical problem in our warehouses. In

addition, I believe that the IoT system can offer more optimal routes during the transportation phase and thus contribute economically and environmentally.

- The participant from Pınar Entegre Et ve Un San. A.Ş. stated that Pınar Et allocates a significant budget to technological investment every year. We give priority to the automation and modernization works of our production facilities. We deliver the products we produce to many points, both domestically and abroad, with the help of a cold chain. Providing real-time control of our integrated facilities and distribution together with IoT investments and minimizing the margin of human error are the reasons for our motivation. In addition, the opportunity to reduce our FLW, thanks to technological inspections, encourages our willingness to invest.
- The participant from Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş. mentioned that the factors that motivate us to use IoT are that we can work systematically because all stages of the procurement process are under constant control, thus saving time. In addition, in case of any problem between processes, it informs us in real-time, enabling us to take immediate action to solve the problem.

Question 19:

In the nineteenth question, participants were asked whether the reduction in investment costs of IoT technology in the coming years would be positive for their future company investment plans. All participants from five companies stated that the reduction in costs in technological investments is positive for their future company investment plans. While only the participants from Sütaş Süt ve Süt Ürünleri A.Ş., Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş., Pınar Entegre Et ve Un San. A.Ş. and Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş. stated that the decrease in investment costs had a positive effect on their investments, Abalıoğlu Lezita Gıda San. A.Ş. also commented on the situation in detail as follow:

- Reduction in investment costs of IoT technology will be very positive for Lezita. Another obstacle is the high investment costs here. Investing in these technologies in Turkey can sometimes be much more expensive than in Europe. How much this investment will reduce costs in the processes considered may not be beneficial in terms of return on investment compared to using labor in the same processes. In macro terms, the exchange rate increases, and the current economic conjuncture are challenging our company in this sense. On the other hand, our company is open to continuous improvement, has a good capital structure, and invests heavily in technology. If investment costs go down, this becomes in many ways a very valuable issue for our investment plans (Abalıoğlu Lezita Gıda San. A.Ş.).

Question 20:

The aim of the last question was to analyze whether participants knew whether the State of the Republic of Turkey had any incentives and contributions to the companies for the spread of technological applications in the industrial sector. The participants from four companies namely Sütaş Süt ve Süt Ürünleri A.Ş., Yiva Zeytin ve Zeytinyağı San. Tic. A.Ş., Pınar Entegre Et ve Un San. A.Ş. and Güres Tavukçuluk Üretim Pazarlama ve Tic. A.Ş. stated that they had no idea whether the State of the Republic of Turkey made any contribution to the companies for the dissemination of technological applications in the industrial sector. Only one participant working in Abalıoğlu Lezita Gıda San. A.Ş. stated that in Turkey there are incentives on certain issues, but these incentives are insufficient on a sectoral basis.

4.1.3. Statistical Analysis

Question 15:

The question was "What is the impact of the company's barriers preventing investment in IoT technology?" to the participants. The frequency section of the table demonstrates that every participant answered this question. None of the participants chose 4 (High) and 5 (Very High) options in this question. Alternative 3 (Fair) received 20% of the vote. In this context, 1 (Very Poor) and 2 (Poor) answers were chosen equally with 40% of the votes each.

Table 4.1. Frequency Table for Question 15

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Poor	2	40.0	40.0	40.0
	Poor	2	40.0	40.0	80.0
	Fair	1	20.0	20.0	100.0
	Total	5	100.0	100.0	

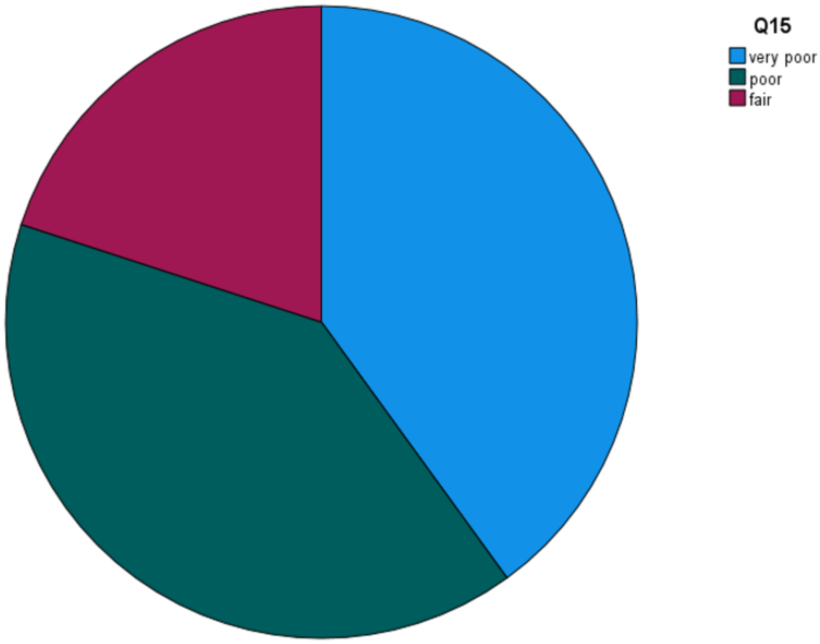

Figure 4.1 Pie Chart for the Frequency Table of Question 15

Question 16:

The question was "What is the economic impact of reducing food loss and waste on your company?". The table's frequency section reveals that every participant responds to this question. None of the participants chose the 1 (Very Poor), 2 (Poor), or 3 (Fair) alternatives in this question. Furthermore, alternative 4 (Good) received 20% of the vote. In this context, with 80% of the vote, the most popular response was 5 (Excellent).

Table 4.2. Frequency Table for Question 16

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Good	1	20.0	20.0	20.0
	Excellent	4	80.0	80.0	100.0
	Total	5	100.0	100.0	

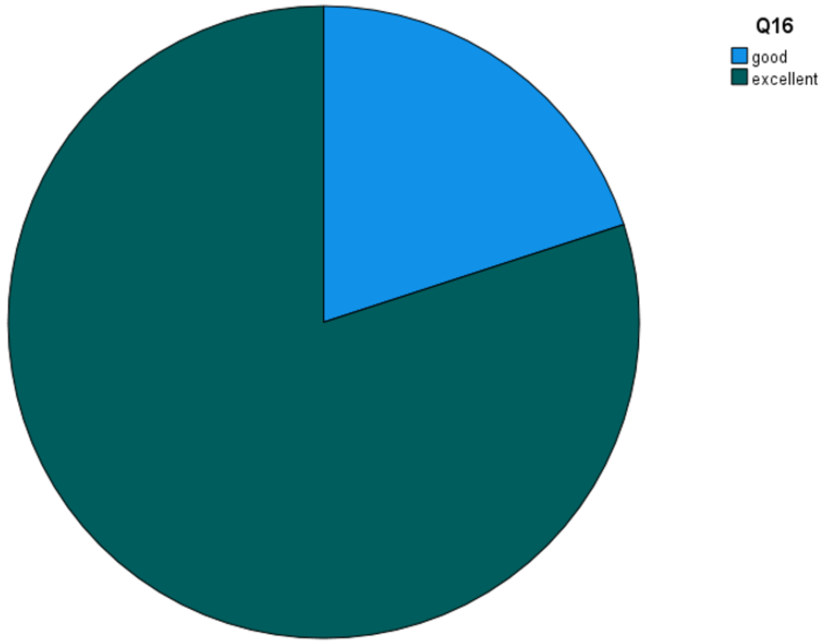

Figure 4.2. Pie Chart for the Frequency Table of Question 16

Question 17:

The question was “What is the effect of the measures taken in reducing your carbon footprint?”. The frequency part of the table shows that all participants answered this question. None of the participants chose the 1 (Very Poor) and 2 (Poor) alternatives in this question. In addition, 3 (Fair) and 4 (Good) alternatives were chosen equally with 20% of the votes each. In this context, the most chosen answer was 5 (Excellent) with 60% of the vote.

Table 4.3. Frequency Table for Question 17

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Fair	1	20.0	20.0	20.0
	Good	1	20.0	20.0	40.0
	Excellent	3	60.0	60.0	100.0
	Total	5	100.0	100.0	

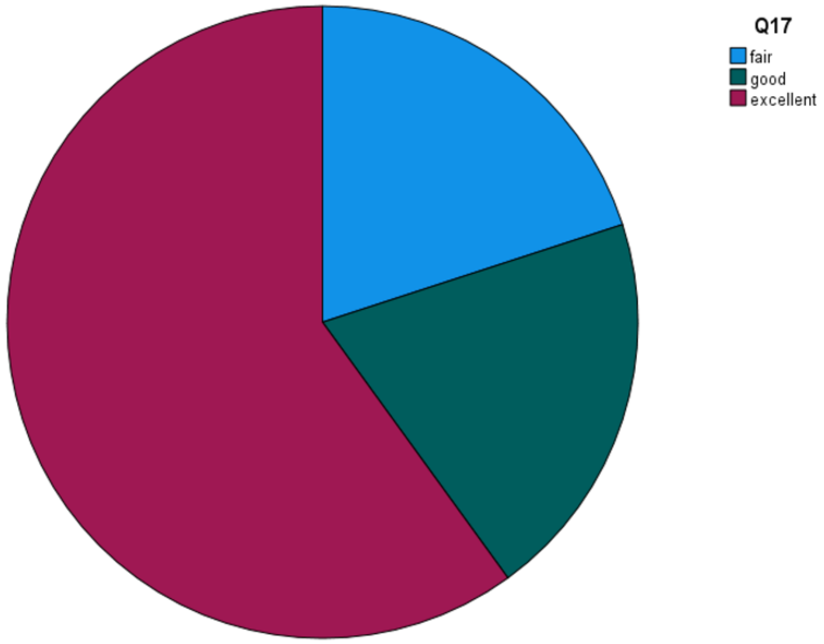

Figure 4.3. Pie Chart for the Frequency Table of Question 17

Question 18:

The question was asked “What is the impact of the IoT technology on your investment in reducing food loss and waste in the procurement process of agricultural products?” to the participants. The frequency part of the table shows that all participants answered this question. None of the participants chose the 1 (Very Poor) and 2 (Poor) alternatives in this question. Furthermore, 3 (Fair) and 4 (Good) alternatives were chosen equally with 20% of the votes each. In this regard, the most chosen answer was 5 (Excellent) with 60% of the vote.

Table 4.4. Frequency Table for Question 18

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Fair	1	20.0	20.0	20.0
	Good	1	20.0	20.0	40.0
	Excellent	3	60.0	60.0	100.0
	Total	5	100.0	100.0	

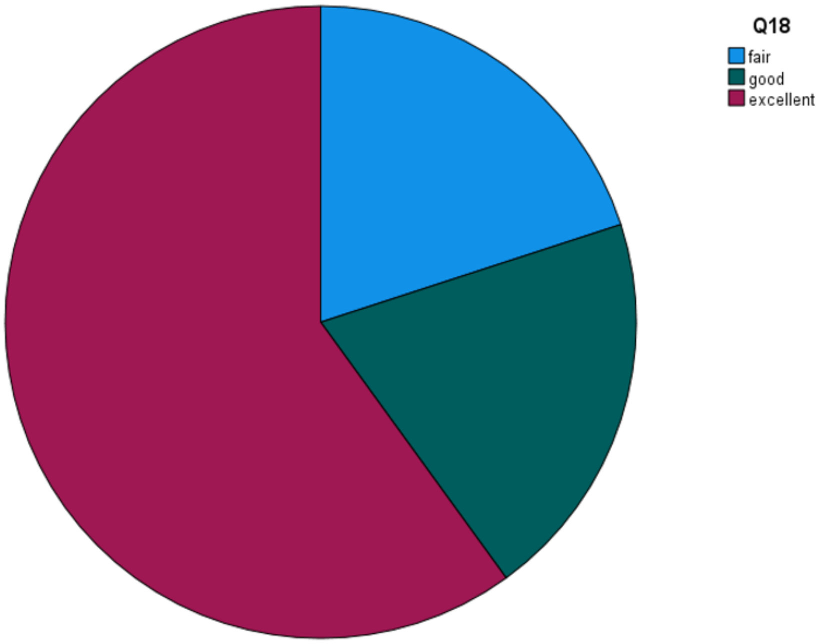

Figure 4.4. Pie Chart for the Frequency Table of Question 18

Question 19:

This question was asked “What is the effect of the IoT applications on the widespread use of the applications in company operations in line with the decreasing costs?” to the participants. The table’s frequency section reveals that every participant responded to this question. None of the participants chose the 1 (Very Poor) and 2 (Poor) options in this question. Also, 3 (Fair) and 4 (Good) options were chosen equally with 20% of the votes each. With 60% of the vote, the most popular response was 5 (Excellent).

Table 4.5. Frequency Table for Question 19

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Fair	1	20.0	20.0	20.0
	Good	1	20.0	20.0	40.0
	Excellent	3	60.0	60.0	100.0
	Total	5	100.0	100.0	

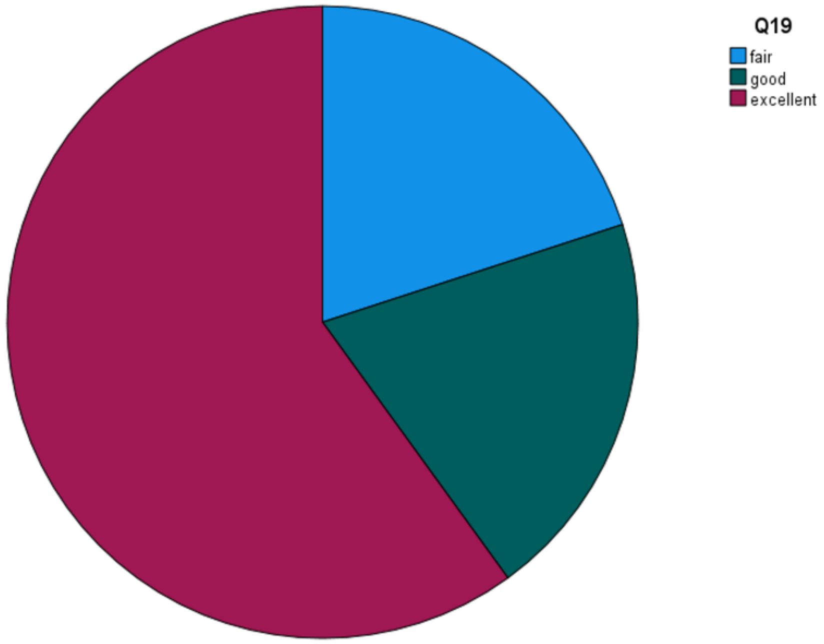

Figure 4.5. Pie Chart for the Frequency Table of Question 19

Question 20:

The question was "If the State of the Republic of Turkey contribution is made to the use of the IoT technology, what is the effect on its dissemination in the industry sector?". The frequency section of the table demonstrates that every participant answered this question. None of the participants chose the 1 (Very Poor) and 2 (Poor) options in this question. In addition, 3 (Fair) and 4 (Good) options were chosen equally with 20% of the votes each. In this context, the most chosen answer was 5 (Excellent) with 60% of the vote.

Table 4.6. Frequency Table for Question 20

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Fair	1	20.0	20.0	20.0
	Good	1	20.0	20.0	40.0
	Excellent	3	60.0	60.0	100.0
	Total	5	100.0	100.0	

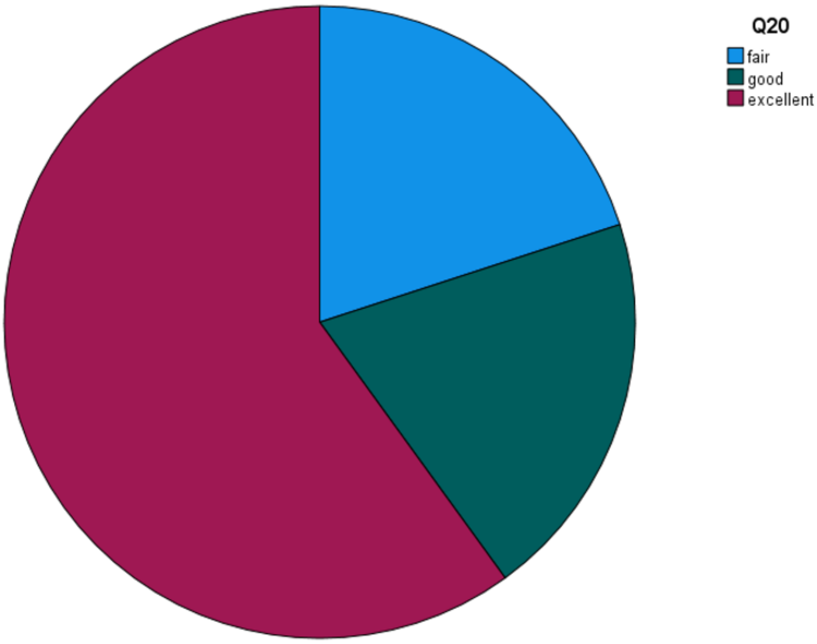

Figure 4.6. Pie Chart for the Frequency Table of Question 20

CONCLUSION AND SUGGESTION

Corporate companies experience more FLW during supply compared to small businesses due to their business volume. Also, corporate companies attach importance to technological investments within the budget opportunity and interest in making profits for future investments. In addition to the investment made, they also have the opportunity to have qualified personnel who can adapt these technologies to business processes or recruit these personnel upon request. In this context, corporate companies are the most important group that implements IoT applications in the supply chain to reduce FLW and achieve better results or are inclined to invest to implement it in the future.

The survey consists of measuring the extent to which corporate companies use IoT technology at which supply chain stage in order to reduce FLW rates in the perishable agri-food product supply chain in Turkey, which is in the category of developing countries, or how much they are willing to invest in IoT technology in the future. Twenty survey questions are asked to participants from five corporate companies that manufacture and export perishable agri-food products involving FLW amount during FSC, third-party supplier selection criteria, parameters that play a role in the deterioration of products, using sensing technology and smart packaging, recycling and reusing, environmental awareness about FLW, detailed production and export process, use of renewable energy, economic impact of FLW, qualified personnel for IoT usage, carbon footprint reduction, applying IoT technology in FSC, the infrastructure of companies for IoT investment, barriers to IoT implementation, motivation to invest in IoT, the impact of low-cost on IoT investment rate, the impact of the State of the Republic of Turkey's contribution to IoT investment. According to the percentages, Open-Ended Questions, Frequency Tables, and Pie Charts used to analyze the responses; firstly these companies include food products whose shelf life has expired, products whose packaging is damaged during supply, products that are not stored at appropriate temperatures during storage and transportation due to technical failure or employee error, products that are stale, broken or damaged, not suitable for consumption, products that are not offered for sale because they do not meet the quality standards of retailers, products obtained from sick animals are categorized as FLW. Considering the survey results, participants agree that IoT technology has a positive impact on reducing or preventing FLW in the supply chain of perishable agri-food products. The sensitive attitudes of corporate companies and white-collar employees towards scarce resources, their investments to reduce the damage they cause to the environment throughout the process (packaging waste, carbon footprint ratios, natural resource utilization rates, etc.) and the sustainable future targets they set for less damage are an undeniable reality. Companies have made great strides in generating electricity from manure and animal waste produced during food production or converting food waste into animal feed. Most of the companies even use certain applications of IoT technologies such as temperature sensors, smart packages, RFID and barcode technologies to ensure food safety and prevent FLW in some processes of the supply chain. However, awareness studies should be carried out to increase the awareness of corporate companies and white-collar employees, to invest in an integrated IoT technology that covers all processes, and to make processes more efficient in reducing FLW.

There are corporate companies that benefit from the services of third-party companies at the logistics stage to export perishable agri-food products. It is important that third-party companies spread their IoT technology applications to their supply processes, as well as corporate companies that supply their own products. According to the survey answers, many companies carry out the transportation of products in refrigerated containers with data loggers, that is, thermometers, which record temperature in order to ensure food safety during the transportation and export phase. However, these devices are notified to companies by the control of the captain or terminal officials, depending on the location where the container breaks down and gives a malfunction report. At this stage, “time” and “transparency” is important criterion in order not to loss or waste the products and to take quick action. It is an undeniable fact that the amount of FLW increased in the time elapsed between people’s realization of the malfunction and informing the company. The most important step in reducing food loss and waste that IoT technology provides to companies is “food traceability”. However, if companies invest in IoT technology, they will be able to access such data from within the company without the need for any human intervention, thanks to sensors that provide instantaneous temperature-humidity status notification, and they will be able to take faster action and reduce FLW while reducing their financial losses at the right rate. Moreover, by interpreting the big data collected by the IoT, they can analyze the supply chain stages of their products for what reason or conditions and make improvements in their processes according to the analysis results. In addition, companies can benefit from smart packaging systems throughout the process from the storage of products to the final consumer. Thanks to these packages, which have freshness sensors and quality indicators on them, they can have real-time information about food safety and quality while extending the shelf life of the food. If there is any problem with food quality, they can take action very quickly. Moreover, these packaging technologies enable consumers to make informed decisions about the quality of the product. In this context, in order to ensure the widespread use of IoT applications in corporate companies, the Government of the Republic of Turkey should provide incentives in this regard and inform the relevant people about these incentives. In this context, in order to ensure the widespread use of IoT applications in corporate companies, the Government of the Republic of Turkey should provide incentives in this regard and inform the relevant people about these incentives.

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APPENDIX 1 – SURVEY

Asya Gizem SAYAR

MA in International Logistics Management - Yaşar University

I am a master's thesis student at Yaşar University in International Logistics Management Department. The subject of my thesis is "Internet of Things Application in an Agricultural Food Supply Chain to Reduce Food Loss and Waste".

This survey aims to reveal how widely the "Internet of Things" or in short IoT technology is used by corporate companies producing and exporting agricultural food products in Turkey to prevent and reduce food loss and waste during the distribution phase of the agricultural supply chain. This study is purely academic and the information you provide will not be shared with any insurance company or any other institution.

In this regard, the survey is divided into three sections: Yes/No Questions, Open-Ended Questions, and 5-point Likert Scale Questions.

Please answer each question in the manner specified in the question.

Please accept my sincere gratitude for taking the time to complete this survey.

1. Select one of the followings to identify your company production area:

- Fresh fruit and vegetable producer/exporter
- Milk and dairy product producer/exporter
- Livestock and livestock product producer/exporter (i.e., eggs, chickens etc.)
- Other

Yes/No Questions

Please circle one of the Yes/No/Undecided options below. If the further explanation or example is required in line with your answer, please fill in the question appropriately.

2. Does your company experience food loss and waste during the supply of perishable products?

Yes/No/Undecided

- If yes, explain at what stages of the procurement process, how often and how much food loss and wastes occur.

3. Is your company environmentally conscious about food loss and waste?

Yes/No/Undecided

4. Do you reuse food losses and wastes generated during the procurement process (i.e., fertilizer in agriculture, organic feed, etc.)?

Yes/No/Undecided

- If yes, give examples of how and in which areas you reuse food lost and waste.

5. Do you supply the product within your own company?

Yes/No/Undecided

- If yes, explain what kind of technological applications you use to ensure food safety in product supply in your company.

- If no, if you are getting services from third-party companies, explain what features you pay attention to when deciding.

6. It uses environmental sensors to monitor parameters such as humidity, temperature, and CO_2 in real-time in the supply chain to reduce food loss and waste. Does your company use such sensing technologies to monitor food quality in the food supply chain?

Yes/No/Undecided

- If yes, give examples of which sensing technologies are used.

7. Do you use smart packaging which consists of sensors and indicators to delay or prevent product deterioration?

Yes/No/Undecided

8. Have you heard of the term "Internet of Things" or in short IoT, which enables smart digital devices to communicate with each other and take and action via the internet?

Yes/No/Undecided

9. Does your company leverage IoT technology throughout the perishable food supply process (i.e., smart transport, smart storage, smart packaging, etc.)?

Yes/No/Undecided

- If yes, explain at what stage of the food supply process you use the IoT technology.

10. Does your company have qualified personnel who have mastered the use of IoT technology?

Yes/No/Undecided

11. Do you think your company infrastructure is sufficient to use the IoT technology in the future?

Yes/No/Undecided

- If no, please explain what you would like to improve your company infrastructure on.

Open-Ended Questions

12. How do your company manufacture and export products and services? Could you give information about the process?
13. Which parameters play a role in the deterioration of the products supplied in your company?
14. At which stage of the product supply chain (production, packaging, storage, transportation) would it be beneficial for your company to use the IoT technology?

5-point Likert Scale Questions

Please circle one of the 1 to 5 answers to the 5-point Likert Scale Questions in the second part of each question below.

15. What are the barriers of your company in using IoT technology?

    b) What is the impact of the company's barriers preventing investment in IoT technology?

Very Poor	Poor	Fair	High	Very High
1	2	3	4	5

16. What are the economic effects of food loss and waste throughout the supply chain on your company?

    b) What is the economic impact of reducing food loss and waste on your company?

Very Poor	Poor	Fair	Good	Excellent
1	2	3	4	5

17. What are the measures you take as a company to reduce your carbon footprint (activities based on carbon dioxide released into the atmosphere)?

    b) What is the effect of the measures taken in reducing your carbon footprint?

Very Poor	Poor	Fair	Good	Excellent
1	2	3	4	5

18. What reasons will motivate you to invest in the IoT application in the future?

    b) What is the impact of the IoT technology on your investment in reducing food loss and waste in the procurement process of agricultural products?

Very Poor	Poor	Fair	Good	Excellent
1	2	3	4	5

19. Would it be positive for your future investment plans to decrease the investment costs of the IoT technology in the coming years?

    b) What is the effect of the IoT applications on the widespread use of the applications in company operations in line with the decreasing costs?

Very Poor	Poor	Fair	Good	Excellent
1	2	3	4	5

20. Is there any contribution made by the State of the Republic of Turkey to ensure the spread of technological applications in the industrial sector?

    b) If the State of the Republic of Turkey's contribution is made to the use of the IoT technology, what is the effect on its dissemination in the industry sector?

Very Poor	Poor	Fair	Good	Excellent
1	2	3	4	5