Exploring Country-Level Factors Impacting Food Loss in the Global Food Supply Chain

Divya Dhirendra Singh

A Thesis

in

The Department

of

Supply Chain & Business Technology Management

Presented in Partial Fulfilment of the Requirements

for the Degree of Master of Supply Chain Management at

Concordia University

Montréal, Quebec, Canada

May 2024

CONCORDIA UNIVERSITY

School of Graduate Studies

This is to certify that the thesis prepared,

By: Divya Dhirendra Singh

Entitled: Exploring Country-Level Factors Impacting Food Loss in the Global Food Supply Chain

and submitted in partial fulfilment of the requirements for the degree of

Master of Supply Chain Management

complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the final Examining Committee:

Dr. Mahdi Mirhoseini	Chair
Dr. Xiaodan Pan	Examiner
Dr. Sara Hajmohammad	Examiner
Dr. Anton Shevchenko	Supervisor

Approved by: Dr. Satyaveer S. Chauhan, Graduate Program Director

Date: May 15th, 2024

Dean: Dr. Anne-Marie Croteau

ABSTRACT

Exploring Country-Level Factors Impacting Food Loss in the Global Food Supply Chain

Divya Dhirendra Singh

Food loss is a major problem throughout the world and there are many reasons why food loss occurs. This research investigates the impact of country level factors on food loss across the harvest, storage, processing, and transportation stages of the global food supply chain. A thorough literature review was carried out to examine various research papers on factors causing food loss and the most pertinent country level factors were chosen for the study. Food loss and country level factors data was obtained for several countries and spanning several years, and multiple regression analysis was carried out. The findings of this research and similar studies in future can have a significant impact on devising policies and fuelling investments to improve food supply chain infrastructure for reducing food loss across the world.

TABLE OF CONTENTS

List of tables

1 INTRODUCTION

Food waste in the food supply chain has drawn attention from all around the world because of its enormous effects on the environment, society, and economy. (Papargyropoulou et al., 2014). According to the Food and Agriculture Organization of the United Nations (FAO), more than 1.3 billion tonnes of food are wasted annually which is 33% of the world's food output. FAO also calculates the Food Loss Index (FLI), which accounts for food loss from the harvesting stage to the retail stage. The FLI for 2016 was about 14%, meaning that 14% of the food was wasted even before it reached the retail outlets. The estimated cost of this wasted food was $400 billion USD.

Often food waste and food loss are used interchangeably, but they are two different terms with distinct definitions provided by FAO. Food waste, according to the FAO, refers to edible food discarded, either after spoiling or exceeding its expiry date. Food loss, on the other hand, pertains to the reduction in weight or quality of food initially produced for human consumption (FAO, 2013). High Level Panel of Experts (HLPE) defines food loss as, "A decrease, at all stages of the food supply chain prior to the consumer level, in mass of food that was originally intended for human consumption, regardless of the cause", and food waste as "food appropriate for human consumption being discarded or left to spoil at consumer level—regardless of the cause" (HLPE, 2014). In this study, we focus on food loss as defined by FAO and HLPE and use it throughout this study.

Food losses can occur because of various reasons in the supply chain, including poor handling and packaging, leaks, threshing-related spoiling, and mechanical damage. (Gustavsson et al., 2011). Food loss not only has a negative effect on food prices, but it also raises farmers' costs and lowers their revenue. (Lipinski et al., 2013; Buzby and Hyman, 2012). Food loss results in the depletion of natural resources that are utilised for production, processing, transportation, and storage, such as land, water, labour, energy, and fuel. Moreover, food production contributes 26% of greenhouse emissions overall, whereas the landfilling of food waste is responsible for 6% of emissions (Amicarelli et al., 2021). The quantity of food produced but not consumed by people is projected to have a carbon footprint of 3.3 gigatonnes (not including greenhouse emissions from land use change). Approximately 2 billion people, or nearly 26% of the world's population, experience moderate to severe food insecurity. By 2050, it is predicted that there will be 9.8 billion people on the planet. It would need a 25–70% increase in food production to satisfy the demands of such a large population (Hunter et al., 2017). To meet the need for food, increasing food production must be accompanied by a reduction in food loss. (Halloran et al., 2014).

Our review of the existing literature suggests that there are many studies focusing on various aspects of food loss. Some of them have studied specific stages (Cardoen et al., 2015, Redlingshöfer et al., 2017., Raak et al., 2017) while others focus on a specific geographical area (Matzembacher et al., 2021, Vittuari et al., 2016, Abdulla et al., 2013). There are also studies which have focused on specific foods or food groups (Brancoli et al., 2019, Delgado et al., 2021, Tostivint et al., 2017, Willersinn et al., 2015). Apart from these, several others are review studies that have focused on identifying food loss causes (Magalhães et al., 2021, Chauhan et al., 2021), identifying food waste hotspots in food supply chain to reduce food loss (Priefer et al., 2016), and using food waste generated in food supply chain for industrial purposes (Girotto et al., 2015). To the best of our knowledge, no existing research has studied country level factors causing food loss globally through all four supply chain stages of harvest, storage, processing, and transportation together. Moreover, we could find no empirical studies consisting of analysis of all four stages. This research aims to fill this gap by investigating the effect of important factors on food loss at the four mentioned stages of the food supply chain across various nations, food categories, and spanning multiple years. By studying all four stages of the supply chain together, our research provides a better understanding of the factors contributing to food loss throughout the entire process, from harvest to transportation. This holistic view allows for a more complete assessment of the problem and potential interventions. The results of our analysis can aid policymakers and government bodies in making necessary changes in food supply chain regulations and investment decisions, prioritizing stages that face higher losses as a result of low investments. Hence this research not only holds academic significance but also carries practical implications.

2 LITERATURE REVIEW

The Food and Agricultural Organization (FAO) has stated that around one-third of all food produced for human consumption, equivalent to 1.3 billion tons of edible food, is lost or wasted annually throughout the entire supply chain (Gustavsson et al., 2011). Developed nations generate food waste owing to consumer eating habits, while developing nations generate food loss due to the inefficient supply chain infrastructure (Mena et al., 2011). To minimize food loss at various stages of the supply chain, it is imperative to understand how to properly manage food supply chains (Mena et al., 2014). This section provides an overview of the food supply chain, its stages, and *what causes* food loss at each stage.

2.1 Food Supply Chain and its Stages

Various definitions of the food supply chain exist. Liu et al. (2013) characterize it as a series of activities from food production to consumption. Mena and Whitehead (2008) provide a supply network perspective, defining it as a network of interactions among farmers, customers, and various food delivery and processing businesses. Folkerts and Koehorst (1998) conceptualize it as the flow of goods and services along the value-added chain of food products with the aim of maximizing consumer value while minimizing costs. Parfitt et al. (2010) distinguish the various stages of the food supply chain, defining it as the collection, transportation, storage, processing, packaging, distribution, and consumption of food.

As these definitions reveal, the food supply chain encompasses every aspect of food production from harvesting to consumption (Wunderlich et al., 2018; Porter et al., 2016). This research distinguishes the following stages in food supply chains (GEP, 2023):

- *Harvest:* The food supply chain starts at this stage, where food is cultivated and then harvested. This stage covers both farming of plants for plant-based products and raising and slaughtering animals for animal-based products. Food cultivation and harvesting often follow strict regulatory requirements to assure its safety, quality, and appearance.
- *Storage:* After harvesting, food undergoes handling and storage processes, tailored to each food item's specific needs. For example, lettuce may be placed in crates for shipment, while potatoes require washing before packaging or further processing into complex food items.
- *Processing:* The processing stage follows, incorporating activities like chopping, pasteurizing, fermenting, and packaging to transform raw agricultural products into more intricate food items.
- *Transportation:* Food products are transported from the storage and processing facilities to their ultimate locations. Adherence to regulatory standards, proper packaging, and timely delivery are pivotal for the overall efficiency of the transportation stage.
- *Consumption:* The final stage of the food supply chain where the consumers buy, prepare, and consume the food. This research, however, does not focus on food loss occurring at this stage of the food supply chain.

2.2 Food loss in supply chains

Food loss has multiple causes, some specific to particular stages of the food supply chain, while others pertain to all stages (Jeswani et al., 2021). The complexity of food supply chains is in part responsible for food loss. Distinct from other supply chains, food supply chains experience various complications because of food’s limited shelf life, interactions between several stakeholders and frequent concerns about food safety, sustainability, and quality (Göbel et al., 2015; Mithun Ali et al., 2019).

The extent of food loss in a country is influenced by its unique economic conditions, infrastructure, and weather patterns. National wealth often can explain variations in food loss between developed and developing nations (Gustavsson et al., 2011; Hodges et al., 2010; Lundqvist et al., 2008). In developing nations, most of the food loss occurs at the early stages of the supply chain due to poor harvesting techniques, transportation limitations, and inadequate storage. Conversely, in developed nations, over 40% of food waste occurs during the consumption stage (Gustavsson et al., 2011).

Inefficiencies within food supply chains further compound the issue of food loss in many nations (Wunderlich et al., 2018). These inefficiencies can manifest at any stage of the supply chain (Hartikainen et al., 2018), and food loss at one stage may be attributable to causes at another stage (Raak et al., 2017). For instance, cosmetic standards imposed by companies at the processing stage contribute to food loss during the harvest stage. Similarly, improper processing and packaging at the processing stage can result in food loss during the transportation stage. Addressing these inefficiencies is widely acknowledged as the most effective strategy for reducing food loss (Hartikainen et al., 2018). Technological advancements have the potential to enhance the overall effectiveness of food supply chains and mitigate food loss (Gustavsson et al., 2011). The subsequent section provides an overview of the causes of food loss at each stage of the food supply chain.

2.3 Food Loss at Each Supply Chain Stage

2.3.1 Harvest

At this stage, food loss can be due to natural and manmade factors. Natural factors such as extreme weather and spoilage often result in food loss during harvesting (Bond et al., 2013). Lack of and excess rainfall has been reported to cause the loss of wheat and maize in China and Guatemala respectively (Delgado et al., 2021). Food loss caused by such factors is often unavoidable. However, there are several man-made factors that contribute to food loss at the harvesting stage. Addressing these factors holds the potential to significantly mitigate such losses. Subsequent paragraphs will delve into country-level factors and their impact on food loss.

Avoidable food loss is a result of improper harvest timing and irresponsible handling of crops amongst other things. Pre-harvest factors influencing losses during harvest include crop variety selection and agronomic techniques such as fertilization and pest/disease control. These could stem from farmers' limited knowledge and inadequate financial resources. In developed nations, food loss during harvesting is lower due to more sophisticated farming methods, better agronomic knowledge, and superior infrastructure. In these nations, the primary causes of food loss during harvesting are overproduction, changing market pricing, lax quality control and strict aesthetic requirements (Kiaya, 2014). Retailers base their specifications mostly on the product's appearance, including size, colour, and lack of bruises or blemishes and often reject products if they do not meet their appearance criteria (Bond et al., 2013; Stuart, 2009). For instance, in Scotland these factors are responsible for 20% to 50% of all vegetable losses (Beausang et al., 2017). Another study identified stringent aesthetic requirements as the cause of 7 to 31% of fruit and vegetable losses in the UK (Porter et al., 2018). Additionally, it emerged as the primary factor contributing to vegetable loss in Germany (Göbel et al., 2015; Krzynowek and Hawkins, 2015). These food losses can be prevented through campaigns and initiatives by the government to create awareness about the safety of these food items and influence consumer behaviour.

According to a study by the European Parliament (2013), another reason for food loss in developed countries is that many farmers sell their produce through "contract farming," which may cause farmers to intentionally produce surpluses in order to prevent undersupplying their clients as a result of unforeseen events like bad weather or insect infestation (Bond et al., 2013). Promoting the adoption of agricultural technologies, such as weather forecasting tools, precision farming techniques, and pest monitoring systems, can enable farmers to make more informed decisions and mitigate risks associated with production uncertainties thereby discouraging contract farming. Not only this, insurance schemes or contingency plans, to help farmers cope with unforeseen events like bad weather or pest infestation can reduce the need for excessive surplus production thereby reducing food loss.

In many developed nations, crops are often left in the field when low market prices cannot cover harvesting efforts and labour costs (Bowman and O'Sullivan, 2018; Johnson et al., 2019). Similar practices occur in Southern China, where "rush harvesting" leads to wheat dumped on fields due to a short harvesting season. In addition, a lack of labour and outdated equipment explains why wheat loss is very high in China (Jiang et al., 2023). Providing adequate support to the farmers in terms of labour, or logistics cost or purchasing the crops and providing a fair market value for the produce can help alleviate the problem of food loss in developed countries. In developing nations, substantial and often avoidable food losses occur during harvesting. Food is lost during harvest when harvesting machinery fails to gather the full item or distinguish between immature and ripe fruit. These losses are often accepted for the sake of cheaper production costs and faster operations (Kantor et al., 1997). Zhang et al. (2021) emphasized the importance of accelerating the construction of more advanced agricultural systems and crop growth monitoring to assure farmers harvest at the appropriate time.

Animal-based products are susceptible to food loss at the harvesting stage owing to various factors. For dairy products, raw milk supply chain losses, while avoidable, result from factors like poor barn conditions, inappropriate feeding and milking techniques, and the use of conventional agricultural methods (Kazancoglu et al., 2018). The integration of advanced techniques enables farmers to reduce these avoidable losses. Kotykova and Babych, (2019) highlighted that reducing post-harvest losses is crucial for addressing food safety issues and increasing the incomes of agricultural enterprises, particularly for low-income households.

2.3.2 Storage

Storage losses, involving spills and spoilage, primarily impact crops, processed goods, and animal products (Alexander et al., 2017). The perishable nature of fresh food necessitates proper post-harvest storage to preserve quality and shield against deterioration caused by mishandling, bacteria, fungus, mildew, and insects. Jain (2007) singles out mishandling as a key contributor to post-harvest losses leading to food being left on the field or package damage (Devin and Richards, 2018; Engström and Carlsson-Kanyama, 2004). Similar to harvesting, storage losses could partly be a result of natural factors which are exacerbated by limited financial resources. Weather conditions at harvest play a significant role for some of the produce, particularly for smallholder farmers in hot climates who rely on sun drying to ensure thorough drying before storage. Substantial crop losses can occur if adverse weather conditions hinder the drying process (Hodges et al., 2011). Financial resources can facilitate the adoption of technologies specifically designed to improve the drying process, such as solar dryers or mechanical dryers. These technologies offer more efficient and consistent drying, irrespective of weather conditions, thereby minimizing the impact of adverse weather on crop losses.

Inappropriate storing often results in the spoilage of over a quarter of all the fruit and vegetables produced (Veena et al., 2011). For example, in India, farmers, lacking necessary precautions, often heap their goods into large cane baskets, exposing them to heat and high temperatures, leading to substantial losses (Otten et al., 2018). Beausang et al. (2017) found that different storage durations for fruits and vegetables affect the amount of loss. For instance, soft fruit, lettuce, and Brussels sprouts do not last as long in storage as leeks, swede, and broccoli do. Another contributing factor is moisture, as fruit does not last as long when it is moist, reducing the time it can be stored after harvesting (Beausang et al., 2017). These losses due to inappropriate storage conditions and mishandling could be because of lack of knowledge or initiative but are certainly preventable.

The lack of refrigeration results in a rapid decline in the value of fruits, vegetables, fish, and livestock goods. In 2014, India encountered a significant shortfall in cold storage capacity, requiring 61.13 million metric tonnes but possessing an actual capacity of approximately 32 million metric tonnes (Times of India, 2014). This lack of cold storage is due to lower financial investments in storage facilities that result in slow construction or improper maintenance of the existing facilities. Proper maintenance of the relative humidity in cold storage facilities is also crucial for preserving the quality of agricultural fresh products and preventing contamination. These facilities also safeguard against losses caused by insect and rodent invasions. Viswanadham (2007) highlights that India's insufficient cold storage facilities directly contribute to a substantial portion of post-harvest food loss. In contrast, roots, tubers, and grain products exhibit lower perishability due to their lower moisture content, although inadequate postharvest treatment can lead to weight and quality losses.

Lack of storage facilities has compelled small business owners in Armenia to use their basements as storage spaces, treating specific regions for fungus and illnesses before each fresh harvest. Many of them are unaware that improper ventilation can lead to the decay of fresh fruit in storage rooms, revealing a lack of expertise or ability to ensure proper post-harvest management and treatment of agricultural goods (Urutyan et al., 2014). Potato producers in Gegharkunik province in Armenia reported a 20% crop loss due to rats in fields and storage rooms after harvest. Another research in China indicates that 15% of grain may be lost in the post-harvest system, with higher storage losses observed for 80% of China's grain stored in homes or subpar granaries by peasants (Liang et al., 1993). These examples clearly demonstrate that not just construction of storage spaces but also their upkeep is extremely crucial to prevent food spoilage and loss.

Dairy products are easily susceptible to spoilage during storage. For example, in Turkey, inadequate storage spaces, due to insufficient technical know-how and financial resources, are the primary cause of raw milk loss. Consequently, substandard storage leads to quality problems that may diminish the market value of milk and potentially pose health concerns (Kazancoglu et al., 2018).

Insufficient infrastructure and storage facilities, including the absence of cold storage, contribute to losses in fruits and vegetables during storage (Li, 2019). A cluster analysis of agricultural products storage infrastructure in Kazakhstan determined the need for storage facilities based on indicators of losses and availability of storage infrastructure, indicating the potential impact of inadequate infrastructure on food loss (Azatbek et al., 2021). The delay in constructing storage warehouses can exacerbate deterioration, leading to increased postharvest losses. Furthermore, Kumar et al. (2021) highlighted that fluctuations in environmental factors, such as temperature, dampness, and longevity, result in significant nutrient losses, which can be further aggravated by delays in constructing appropriate storage facilities.

2.3.3 Processing

Processing of food involves various procedures, including peeling, slicing, trimming, cutting, grinding, boiling, heating, and packaging. Crop and meat losses occur during various industrial processing stages. Some losses during processing are inevitable, such as whey from the making of cheese and fruit pomace from the creation of juice or wine while others occur due to such factors as process inefficiencies and poor-quality control requirements (Dora et al., 2019; WRAP, 2015). Equipment failure can further contribute to process inefficiencies by increasing the risk of bacterial contamination and food spoilage (Mena and Whitehead, 2008). Poor quality control requirements lead to finished products with flaws in form, size, weight, or damaged packaging (Papargyropoulou et al., 2014). Products with damaged packaging may be more susceptible to spoilage during transportation while other flaws may cause the products to be rejected by processors, retailers or consumers leading to food loss.

The percentage of crops that are lost during processing ranges from 15 to 59% depending on the food category (Alexander et al., 2017). Estimates from a recent UK study reveal that food processing industry contributes to an annual food loss of 2.17 Mt. Vegetables, starchy roots, and cereals constitute the largest source, followed by meat, fish and dairy products (Jeswani et al., 2021). Having high-quality refining allows for reducing losses at the processing stage (Liu et al., 2013). Viswanadham (2007) highlighted the absence of suitable infrastructure for processing and cold storage in developing nations like India as a major cause of food loss. India lacks advanced processing techniques, but efforts by the government, including a five-year tax break and 100% foreign direct investment in the food processing industry, aim to make contemporary processing techniques more accessible (MOFPI, 2014). In developing nations, inadequate infrastructure leads to fresh vegetable losses ranging from 20% to 50% (Verma & Singh, 2004). A study in Armenia reveals that some processors operate on Soviet-era processing facilities, while others use fully restored production lines and equipment.

The use of outdated machinery contributes to increased produce wastage during processing (Urutyan et al., 2014).

Loss of animal-based products during the processing stage can occur due to substandard quality of the ingredients, particularly if they fail to meet safety standards or are processed under unsanitary conditions (Karwowska et al., 2021). Milk losses result from spills in processes like pasteurization. Overall, processing losses for animal-based products stem from inadequate planning, contamination, sick animals, quality rejections, and legal factors (Mena et al., 2014).

Inadequate processing techniques, limited line capacity, and frequent modifications made to the food produced in processing facilities are some of the causes contributing to food loss (HLPE, 2014; Beretta et al., 2013; Murthy et al., 2009). Human errors, such as incorrect process management also contribute to food loss (Raak et al., 2017). Many of these issues can be avoided by staff training, process standardization and upgrading equipment all of which require financial investment in the processing sector. When organizations face budget constraints and are unable to procure advanced and robust equipment, the risk of breakdowns and malfunctions increases, which in turn leads to food loss. Geylani & Stefanou (2012) found that investment spikes significantly impact productivity growth in food manufacturing plants, suggesting that decreased investment may lead to reduced productivity and potentially contribute to food loss during processing.

2.3.4 Transportation

During transportation, mechanical damage poses a risk, potentially resulting in package deformation, product rejection, or decreased appeal to recipients. Ineffective transportation jeopardizes food safety and exacerbates occurrences of food loss within the supply chain. Liu et al. (2022) reveal several ways transportation can be ineffective. First, the transportation equipment can be outdated and inadequate, which could contribute to food loss by exposing perishable goods to unfavourable conditions, causing physical damage, and leading to delays during transportation, causing food decay. Second, the poor state of roads, especially those connecting farming communities, can damage the produce. Third, prolonged breakdowns, construction work, and other issues extend lead times, can undermine the quality of perishable commodities. Furthermore, a study by Bilska et al. (2016) identified issues with transportation and container conditions during the movement of goods between marketplaces, substantiating the significance of transporters in contributing to food loss and damage. These issues underscore the importance of development of transportation and road infrastructure in mitigating food spoilage and food loss.

Incorrect placement or improper packaging size of fresh produce in punnets or cartons during transportation can lead to natural abrasions, impacts, or compressions (Li and Thomas, 2014; Mena et al., 2014) which can cause damage to the soft tissue in fruit and vegetables that is particularly susceptible to mechanical injury, contributing significantly to food loss (Beretta et al., 2013; Gustavsson and Stage, 2011; WRAP, 2010). Significant transportation damages can result in food ending up in unprocessable, unsellable, or inedible states (Halloran et al., 2014; Janssen et al., 2014a).

Jeswani et al. (2021) calculated that 1.23 Mt of food loss, constituting 9% of the total annual food loss in the UK, occurs during transportation, employing the approach outlined by Gustavsson et al. (2013). Challenges arise with frozen or chilled food products, as poor cold chain management frequently leads to food loss (ARC, 2012; Mena et al., 2008). For instance, obtaining refrigerated vehicles in India for the delivery of perishable foods is challenging, with only 5% of perishable food items being moved by temperature-controlled trucks. Maheshwar & Chanakwa (2006) reveal that 40 million tonnes of fruit and vegetables are lost annually due to cold chain gaps, including inadequate transportation facilities. Unnecessary delays at state crossings further increase operating costs for refrigerated vehicles (ITLN, 2015). While purchasing refrigerated trucks requires significant upfront investment, the long-term savings from reducing food loss might outweigh the costs.

In China and Armenia factors contributing to food loss during transportation include the distance from primary food markets, financial constraints impeding self-delivery, adverse selling conditions (such as heat and humidity), and the short expiration dates of dairy products (Jiang et al., 2023, Urutyan et al., 2014). Expiration dates shorten when travel time and distance exceed the ripening process, reducing commercialization chances, and leading to customer rejection of some provided food. Loss of meat products during transportation is attributed to exposure of the cargo to adverse weather conditions during loading and unloading, lack of refrigerated vehicles, and transportation delays (Karwowska et al., 2021). To reduce food losses during transportation, Chen et al. (2018) offer potential policy decisions, suggesting the importance of investment in transport equipment to minimize food loss during transportation.

3 HYPOTHESIS DEVELOPMENT

Based on the literature (e.g. Jiang et al., 2023, Zhang et al., 2021, Kotykova and Babych, 2019), food loss at the harvest stage can be attributed to both natural and man-made factors. Natural factors such as extreme weather conditions are often unavoidable. However, man-made factors, including improper harvest timing and irresponsible handling of crops, significantly contribute to avoidable food loss. For instance, in developed nations, sophisticated farming methods and better infrastructure reduce harvest losses, while in developing nations, a lack of advanced farming methods, agronomic knowledge and poor infrastructure, lead to substantial losses. Successful interventions require substantial investments in agriculture, either through government initiatives or private sector involvement, ensuring the implementation of modern farming technologies. This effort will minimize food losses and contribute to the overall resilience and sustainability of the agricultural sector. Formally,

Hypothesis 1: The insufficient development of agricultural infrastructure increases food loss at the harvesting stage.

From the previous literature (e.g. Veena et al., 2011, Beausang et al., 2017, Urutyan et al., 2014), food loss during the storage stage is influenced by several factors including mishandling, technological shortcomings, and biological deterioration. In developing nations, these issues are exacerbated by a lack of infrastructure and technological resources. Addressing these challenges requires comprehensive interventions, including investments in advanced storage technologies, improved infrastructure, and the implementation of best storage practices, thereby ensuring a more sustainable and resilient food supply chain.

Formally,

Hypothesis 2: The insufficient development of storage infrastructure increases food loss at the storage stage.

The processing stage involves transforming raw agricultural products into more complex food items. Studies (e.g. Beretta et al., 2013; Murthy et al., 2009, Karwowska et al., 2021) have shown that food loss at this stage could be a result of natural processing phenomena, but it could also be due to avoidable factors like inefficient processing techniques, outdated machinery, machine failure and spills and contamination. Developing countries struggle with outdated processing equipment and techniques and there is a need for technological advancements, improved infrastructure, and enhanced quality control measures to mitigate these losses effectively. Investing in modern processing facilities can help reduce food loss during processing.

Formally,

Hypothesis 3: The insufficient development of industrial and technological infrastructure increase food loss at the processing stage.

Transportation is critical in moving food products from storage and processing facilities to their final destinations. The existing literature shows (e.g. Bilska et al., 2016, Jiang et al., 2023, Halloran et al., 2014), that losses during this stage can occur due to improper packaging, delays, and inadequate transportation conditions. Food losses occur due to inefficient logistics and strict delivery schedules, poor transportation infrastructure and lack of proper vehicles. To reduce food loss at the transportation stage, investment in modern transportation equipment, infrastructure improvement, and efficient cold chain management are essential. Improved road conditions, streamlined logistics, and investments in refrigerated vehicles can contribute significantly to minimizing food loss during transportation, ensuring the safe and timely delivery of goods to consumers.

Formally,

Hypothesis 4: The insufficient development of transportation infrastructure increases food loss at the transportation stage.

4 METHODOLOGY

4.1 Data collection and cleaning process

We examine our hypotheses utilizing secondary data obtained from various reputable sources, including the Food Loss and Waste database, FAOSTAT, World Bank, and OECD database. The dataset on food loss and waste is derived from openly accessible databases, reports, and studies that assess these issues across diverse food products, stages of the value chain, and geographical regions. Compiled as of November 2021, this dataset incorporates information from over 700 publications and reports, drawing from a variety of sources such as subnational reports, academic studies, FAOSTAT, and reports issued by national and international organizations such as the World Bank, GIZ, FAO, IFPRI, among others.

FAOSTAT is a key source for statistical data related to food and agriculture in 245 countries and 35 regional areas, spanning the period from 1961 to the most recent available year. The data coverage encompasses various aspects, including agricultural production, forestry, trade, prices, investment, as well as emission and agri-environmental indicators. The World Bank contributes data on numerous World Development Indicators (WDI) compiled from officially recognized international sources, providing the most current and accurate global development data with estimates at national, regional, and global levels. The OECD, recognized as a statistical agency, disseminates comparable statistics on a wide range of subjects. These statistics are available through interactive charts on the OECD data portal, interactive databases, and static or dynamic files.

The primary benefit of the Food Loss and Waste database is its capacity to gather data in bulk, simplifying extensive empirical analyses. In the scope of our analysis, we specifically concentrated on four key value chain stages—harvest, storage, processing, and transportation. The selected basket items for examination included Cereals and pulses, Fruits and vegetables, Oilseeds and roots, and Animal and animal products. The temporal focus extended from 2001 to 2022, utilizing food loss data within this timeframe. It is noteworthy that the number of countries subject to analysis varies across stages, with 70 countries for the harvest stage, 62 for the storage stage, 54 for the processing stage, and 46 for the transportation stage.

Similarly, the FAOSTAT website provides information on the agriculture share of government expenditure and agriculture value added share of GDP. The data for both metrics is presented as percentages and encompasses 288 countries. The time frame extends from 2001 to 2021. The World Bank website offers data on the time required to build a warehouse and manufacturing value added (% of GDP). Data on the time required for warehouse construction is provided in 'days' and covers 266 countries from 2005 to 2019, while information on manufacturing value added (% of GDP) is presented as a percentage, encompassing data for 266 countries from 2001 to 2022. Additionally, data on transport infrastructure investment and maintenance can be obtained from the OECD database. The currency unit for both datasets is Euros. The data on transport infrastructure investment encompasses investments in rail, road, sea, inland waterways, and air infrastructure, covering 55 countries and ranging from 2001 to 2021. Similarly, the data for transport infrastructure maintenance, covering rail, road, sea, inland waterways, and air infrastructure, spans 52 countries over the same period from 2001 to 2021.

After the data collection procedure, we preregistered our hypotheses on the Open Science Framework (OSF) platform (https://osf.io/). The process involved specifying the research questions, hypotheses, study design, planned analyses and information about the data source apart from other things. The registration DOI is mentioned in the Appendix.

4.2 Dependent variable

The dependent variable in this analysis is the food loss percentage at the harvest, storage, processing, and transportation stages of the supply chain. Food Loss and Waste database calculates the food loss percentage by employing a model that incorporates the national average percentage for each crop and year with multiple estimates. This percentage, delineated across the various stages in the supply chain, is subsequently applied to a reference quantity and deducted from the remaining quantity of the preceding stage. The choice of utilizing food loss percentage as the dependent variable in this analysis is grounded in its effectiveness as a comprehensive metric for assessing and quantifying the impact of various factors at distinct stages of the supply chain. Food loss percentage provides a succinct and measurable indicator of the proportion of food lost relative to the total quantity produced, offering insights into the efficiency and vulnerabilities of the supply chain. This metric not only encapsulates the overall magnitude of losses but also allows for a nuanced examination of specific stages, such as harvest, storage, processing, and transportation. By focusing on the percentage of food lost at each stage, the analysis can discern patterns, trends, and critical points of vulnerability within the supply chain, thereby facilitating targeted interventions and informed decision-making.

4.3 Independent variables

At the harvest stage, the independent variables encompass the agriculture share of government expenditure and agriculture value added share of GDP. Regional disparities in economic development are associated with differences in infrastructure investment, crucial for agriculture and rural development (Chaminuka et al., 2008). Government investment in agriculture infrastructure has proven instrumental in fostering the adoption of innovative technologies (Chekunov, 2019). Additionally, the establishment and growth of agribusiness infrastructure play pivotal roles in facilitating effective interaction among agricultural actors, fostering the growth and development of agricultural products (Stukach et al., 2019). For the storage stage, the independent variable is represented by the time required to build a warehouse. Literature suggests that scientific storage methods can notably diminish storage losses (Kumar & Kalita, 2017). Timely availability of warehouses is essential, as delays in infrastructure development may contribute to increased food loss. Silos and warehouses, in comparison to traditional facilities, are identified as effective means to mitigate storage losses, with the absence of proper storage facilities being a significant contributor to postharvest losses (Zhang et al., 2021; Koizumi, 2018). The processing stage is characterized by the independent variable of manufacturing (value added as a percentage of GDP). Prior studies indicate a potential link between manufacturing infrastructure and economic outcomes, emphasizing that reducing food losses in sub-Saharan Africa could lead to increased farm incomes (Aragie et al., 2018). The significance of infrastructure for manufacturing activities is underscored by findings demonstrating that infrastructure development and capacity utilization significantly impact manufacturing value added (Edeme et al., 2020). At the transportation stage, the independent variables comprise transport infrastructure investment and transport infrastructure maintenance. Investment in reliable transport infrastructures has been shown to reduce post-harvest losses (Doliente & Samsatli, 2021). Limited investment in physical infrastructure, such as roads and cold chain facilities, can enhance the role of intermediaries and contribute to increased food loss during transportation, particularly in developing countries (Kanani, 2019).

Table 1 List of independent variables included in the data analysis and their descriptions.

Variable	Description
Agriculture value added share of GDP	The agriculture value-added share of GDP represents the percentage contribution of the agricultural sector's net output, accounting for inputs and depreciation, to the total Gross Domestic Product (GDP) of a country. Agriculture pertains to ISIC divisions 1-5, encompassing forestry, hunting, fishing, crop cultivation, and livestock production.
Agricultural share of government expenditure	It is the percentage of a government's total budget allocated specifically to agricultural-related activities. Agriculture encompasses the sector comprising agriculture, forestry, fishing, and hunting. Government Expenditure includes all expenses and the acquisition of non-financial assets dedicated to supporting a specific sector, as outlined in the Government Finance Statistics Manual (GFSM) 2014, formulated by the International Monetary Fund (IMF).
Time required to build a warehouse (days)	It refers to the total number of calendar days essential to accomplish the prescribed procedures for warehouse construction. In instances where expediting a procedure incurs

	additional expenses, the selection of the quickest procedure is made, irrespective of cost considerations.
Manufacturing, value added (% of GDP)	Manufacturing, value added (% of GDP) signifies the percentage of a country's Gross Domestic Product (GDP) that is contributed by the manufacturing sector after accounting for inputs and depreciation. Manufacturing encompasses industries falling within ISIC divisions 15-37 (includes food). The value added represents the net output of a sector, obtained by summing up all outputs and subtracting intermediate inputs. This calculation is performed without accounting for the depreciation of fabricated assets or the depletion and degradation of natural resources.
Transport infrastructure investment	Infrastructure investment pertains to expenditures on both new transport construction and enhancements to the existing network, serving as a crucial factor influencing performance in the transport sector. Inland infrastructure encompasses road, rail, inland waterways, maritime ports, and airports, considering all financing sources. The indicator is assessed as a percentage of GDP for total inland investment and in euros for specific components such as road, rail, air, inland waterways, and sea.
Transport infrastructure maintenance	Infrastructure maintenance encompasses expenses allocated to the preservation of the current transport network, specifically focusing on maintenance expenditures funded by public administrations. The indicator is quantified in euros and delineated into components for road, rail, total inland, air, and sea.

4.4 Control variables

In our analysis, we incorporate three control variables to mitigate the risk of deriving erroneous estimates. To investigate the impact of country-level factors on food loss across the stages of the global food supply chain, it is essential to consider country, food basket type, and year as control variables. The insufficient development of agricultural, storage, processing, and transportation infrastructure can lead to increased food loss at each stage of the supply chain (Parfitt et al., 2010).

The limited data suggest that losses are much higher at the immediate post-harvest stages in developing countries and higher for perishable foods across industrialized and developing economies alike (Abiad & Meho, 2018). The level of funding allocated to post-harvest systems and the development of infrastructure significantly impact food loss and differs for different countries (Parfitt et al., 2010). Additionally, the impact of the COVID-19 pandemic on food security and the economy varies from country to country, depending on the volume of agricultural production (Ahmed et al., 2021; Khawar et al., 2021). Furthermore, the economic impact of food loss and waste has been estimated to be substantial in certain countries, emphasizing the need to consider country-specific economic factors (Brenes-Peralta et al., 2021).

Food basket types vary across regions, representing the assortment of crops and products central to the local diet. Considering food basket types as a control variable helps capture the unique characteristics of each region's agricultural output and consumption patterns, providing a more nuanced understanding of food loss dynamics. Variability in food types and quantities can influence the level of food loss, as different foods have distinct perishability and storage requirements (Hardman et al., 2015). Additionally, the integration of knowledge about where, for which foods, and in which countries the greatest losses occur is essential to target efforts effectively (Nicastro & Carillo, 2021). Controlling for food basket type helps to account for the diversity in storage requirements based on the types of crops and food products prevalent in each region. This ensures that the impact of transportation infrastructure on food loss is assessed within the context of the specific food basket composition (Corrado et al. 2017, Sobhani & Babashahi, 2020, Wang, 2023). By considering the specific food basket type, the research can effectively capture the varying storage and transportation needs of different food products, thereby providing a comprehensive understanding of the factors influencing food loss in the transportation stage.

The inclusion of the variable "year" as a control factor is essential for acknowledging temporal shifts and changes in policies, technologies, and global economic conditions that may influence food loss trends over time. By controlling for year, researchers can discern whether observed changes in food loss are attributed to country-level factors or broader temporal trends. The impact of historical events, such as the Russia-Ukraine conflict, can trigger significant disruptions in global food supply chains, affecting food loss levels (Jagtap et al., 2022). Additionally, the level of impact of COVID-19 on food security differs from country to country, indicating the importance of considering the specific year and its associated events when investigating food loss (Ahmed et al., 2021; Khawar et al., 2021).

4.5 Data examination

Data examination was performed for all dependent and independent variables by using multiple approaches. Descriptive statistics like mean, standard deviation and min-max values provided insights into the central tendency and variability of the variables. Correlation analysis was carried out between the dependent and independent variables for all pairs to check the strength and direction of the relationship and to establish if the relationship is linear. Density plots were used to visualize the data which revealed skewed distributions in certain variables. To correct the skewness and make the data more symmetric, log transformations were performed for the skewed variables. The transformation helped to normalize the data and enhanced the interpretability of the relationships between variables.

4.6 Descriptive Statistics

The descriptive statistics for all the dependent and independent variables are as shown in Table 2. The values offer an understanding of the data's characteristics and provide guidance for further analysis.

Table 2 Descriptive Statistics for dependent and independent variables

Dependent variables	**Mean**	**SD**	**Min**	**Max**	**No. of obs**
Loss percentage at harvesting stage	5.395	3.975	0.350	43.000	-
Loss percentage at storage stage	4.036	5.832	0.599	45.000	-
Loss percentage at processing stage	5.813	6.712	0.008	32.855	-
Loss percentage at transportation stage	3.160	3.701	0.128	10.500	-
Independent variables	**Mean**	**SD**	**Min**	**Max**	
Agriculture value added share of GDP (t-1) (million USD)	19952.500	80255.810	66.400	1146203.000	566
Agriculture value added share of GDP (t-2) (million USD)	19305.100	82056.830	66.400	1211889.200	566
Agricultural share of government expenditure (t-1) (%)	4.571	3.805	0.120	24.710	661
Agricultural share of government expenditure (t-2) (%)	4.596	3.779	0.120	24.710	661
Time required to build a warehouse (t-1) (days)	177.100	80.178	53.500	566.000	317
Time required to build a warehouse (t-2) (days)	182.400	81.903	53.500	566.000	317
Manufacturing, value added (% of GDP) (t-1) (%)	13.992	6.805	4.475	32.452	63

Manufacturing, value added (% of GDP) (t-2) (%)	13.991	6.969	4.981	32.094	63
Transport infrastructure investment (t-1) (million Euro)	40491.000	143415.200	1100.000	615000.000	18
Transport infrastructure investment (t-2) (million Euro)	39493.000	143661.800	1086.000	615000.000	18
Transport infrastructure maintenance (t-1) (million Euro)	5704.300	2196.529	919.800	9299.000	17
Transport infrastructure maintenance (t-2) (million Euro)	5452.500	2662.492	807.800	9380.200	17

4.7 Correlation Analysis

We carried out a correlation analysis to investigate the relationship between the dependent and independent variables for each stage of the food supply chain. Negative correlations were observed for all pairs with varied confidence levels. A strong negative correlation was found between manufacturing value added as a percentage of GDP (t-1) and (t-2) and losses at the processing stage, suggesting that a higher manufacturing contribution to GDP might help reduce losses during processing.

Table 3 Correlation Analysis values for dependent and independent variables

Construct: Development at harvesting stage	Food loss percentage at Harvesting[1]	Agriculture value added share of GDP[1] (t-1)	Agriculture value added share of GDP[1] (t-2)
Food loss percentage at Harvesting[1]	1	-0.0941*	-0.091*
Agriculture value added share of GDP[1] (t-1)	-0.0941*	1	0.993
Agriculture value added share of GDP[1] (t-2)	-0.091*	0.993	1
Construct: Development at harvesting stage	Food loss percentage at Harvesting[1]	Agricultural share of government expenditure[1] (t-1)	Agricultural share of government expenditure[1] (t-2)
Food loss percentage at Harvesting[1]	1	-0.049	-0.044
Agricultural share of government expenditure[1] (t-1)	-0.049	1	0.897***

Agricultural share of government expenditure[1] (t-2)	-0.044	0.897***	1
Construct: Development at storage stage	Food loss percentage at Storage[1]	Time required to build a warehouse[1] (days) (t-1)	Time required to build a warehouse[1] (days) (t-2)
Food loss percentage at Storage[1]	1	-0.136*	-0.105
Time required to build a warehouse (days)[1] (t-1)	-0.136*	1	0.951***
Time required to build a warehouse (days)[1] (t-2)	-0.105	0.951***	1
Construct: Industrial and technological infrastructure	Food loss percentage at Processing[1]	Manufacturing, value added (% of GDP)[1] (t-1)	Manufacturing, value added (% of GDP)[1] (t-2)
Food loss percentage at Processing[1]	1	-0.426***	-0.328**
Manufacturing, value added (% of GDP)[1] (t-1)	-0.426***	1	0.952***
Manufacturing, value added (% of GDP)[1] (t-2)	-0.328**	0.952***	1
Construct: Development at transportation stage	Food loss percentage at Transportation	Transport infrastructure investment[1] (t-1)	Transport infrastructure investment[1] (t-2)
Food loss percentage at Transportation	1	-0.190	-0.091
Transport infrastructure investment[1] (t-1)	-0.190	1	0.984***
Transport infrastructure investment[1] (t-2)	-0.091	0.984***	1
Construct: Development at transportation stage	Food loss percentage at Transportation	Transport infrastructure maintenance (t-1)	Transport infrastructure maintenance (t-2)
Food loss percentage at Transportation	1	-0.033	-0.051
Transport infrastructure maintenance (t-1)	-0.033	1	0.965***
Transport infrastructure maintenance (t-2)	-0.051	0.965***	1

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

[1]: log transformed variables

5 RESULTS

5.1 Harvest Stage (Hypothesis 1)

Agriculture value added share of GDP

We conducted a multiple linear regression analysis, incorporating lagged independent variables (one and two-year lags, represented as (t-1) and (t-2)), to explore the relationship between agricultural infrastructure development and the percentage of food loss at the harvesting stage. The independent variable used to measure agricultural infrastructure development was the agriculture value added share of GDP. The analysis was based on a dataset comprising 566 observations across various countries and years. The mean food loss percentage at the harvest stage was approximately 5.39%, ranging from 0.35% to 43.00%. We employed a linear regression model with log-transformed food loss percentage as the dependent variable and log-transformed agriculture value added share of GDP values of the last two years as independent variables. Country, year, and basket items (a categorical variable representing different types of agricultural products) were used as control variables. These control variables remain the same throughout and have been used in all hypotheses. The coefficient estimate for log-transformed agriculture value added share of GDP (t-1) was found to be 0.070. This suggests that there is a positive relationship between the agriculture value added share of GDP in the previous year and food loss percentage at the harvesting stage and as the agriculture value added share of GDP (t-1) increases, the food loss percentage also tends to increase. However, since the p-value is 0.400 (> 0.05), we cannot conclude that this relationship is significant. Similarly, a positive coefficient of 0.031 was observed for log-transformed agriculture value added share of GDP (t-2) which suggests that an increase in investment two years ago is associated with a slight increase in the log-transformed food loss percentage holding other variables constant. However, like the coefficient for investment one year ago, this coefficient is not statistically significant having a p-value of 0.705. The regression model demonstrated decent fit, with an R-squared value of 0.585, indicating that approximately 58.5% of the variance in log-transformed food loss percentage was explained by the independent variables.

To address potential outliers and non-normality in the data, we employed a robust regression method. The robust regression analysis revealed that the coefficients for log transformed agriculture value added share of GDP (t-1) and (t-2) were both 0 with corresponding t-values of 2.192 and -0.724 respectively. Although the estimate for agriculture value added share of GDP (t-1) is statistically significant it does not explain the variations in the loss percentage at harvesting stage of the current year whereas the other value isn't significant. This suggests that agriculture value added share of GDP of the last one and two years may not be helpful in explaining the variations in the loss percentage at harvesting stage of the current year. The extremely small and positive residual standard error suggests that the model fits the data very well.

We used a panel regression model in addition to the robust regression analysis to further investigate the relationship. The model revealed a coefficient estimate of 0.056 for log-transformed agricultural value-added share of GDP (t-1), indicating a potential increase in food loss percentage with the increase in agricultural value-added share of GDP in the previous year and a coefficient estimate of -0.035 indicating a slight decrease in the food loss percentage with agricultural value-added share of GDP two years ago. However, the p values indicated that these values are not statistically significant. Further research may be warranted to explore additional factors that contribute to food loss at the harvesting stage.

Overall, based on these results, we cannot conclude that there is a significant relationship between agriculture value added share of GDP and food loss at the harvesting stage. The coefficients lack statistical significance, suggesting that there may be other factors at play or that the relationship is not adequately captured by the models used.

Agriculture share of government expenditure

Another proxy used to test the hypothesis at the harvesting stage was the agricultural share of government expenditure which had 661 observations from various countries and years. We carried out linear regression with log-transformed food loss percentage at harvesting stage as the dependent variable and log-transformed agricultural share of government expenditure values of the last two years as independent variable. We obtained a coefficient estimate of -0.043 which suggests a negative relationship between log-transformed agricultural share of government expenditure (t-1) and log-transformed food loss percentage at the harvesting stage. However, the high p-value of 0.301 indicates that this relationship is not statistically significant. Also, for the variable agricultural share of government expenditure (t-2) the coefficient of -0.012 was observed which suggests that an increase in agricultural share of government expenditure two years ago would result in a decrease in the current food loss percentage. Like the previous coefficient, this coefficient is not statistically significant with a p-value of 0.766. The regression model demonstrated an overall good fit, with an R-squared value of 0.617.

Next, we used a robust regression model which yielded a coefficient estimate of 0 for both the variables log-transformed agricultural share of government expenditure (t-1), (t-2) indicating that there is no observed effect of this variable on the log-transformed loss percentage. Also, the t-values for both theses coefficients suggest that they are not statistically significant. Additionally, a small positive value for residual standard error indicates a good fit of the model to the data.

The results of the panel regression model analysis revealed a coefficient estimate of -0.052 and -0.043 for log-transformed agricultural share of government expenditure (t-1) and (t-2) respectively, indicating a that an increase in agricultural share of government expenditure one and two years ago decreases food loss percentage in the current year at the harvesting stage. However, the p-values indicate both values are not significant which suggests that agricultural share of government expenditure alone may not be a significant predictor of food loss at the harvesting stage, after controlling for individual effects.

As the coefficients for lagged, robust and panel regressions were not statistically significant we can conclude that there is insufficient evidence to support that lower agricultural share of government expenditure increases food loss at the harvesting stage.

Based on the analysis carried out with both the proxies for 'development of agriculture infrastructure' we can conclude that the results do not support our hypothesis that insufficient development of agricultural infrastructure increases food loss at the harvesting stage.

Table 4 Results of regression analysis for hypothesis 1

OLS REGRESSION	**Dependent Variable (Food loss percentage at Harvesting)**	
Independent variable	Coefficient (std. error)	Coefficient (std. error)
Agriculture value added share of GDP (t-1)	0.070 (0.083)	-
Agriculture value added share of GDP (t-2)	0.031 (0.082)	-
Agricultural share of government expenditure (t-1)	-	-0.042 (0.041)
Agricultural share of government expenditure (t-2)	-	-0.011 (0.039)
Year	Included	Included
Country	Included	Included
Basket Items Fruits & Vegetables	0.475*** (0.087)	0.478*** (0.079)
Basket Items Meat and Animal Products	-1.580*** (0.184)	-1.332*** (0.145)
Basket Items Roots, Tubers & Oil-Bearing Crops	-0.212* (0.096)	-0.116 (0.084)
R square	0.585	0.617

F value	10.850	14.070
No. of observations	566	661

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 5 Results of robust regression analysis for hypothesis 1

ROBUST REGRESSION	**Dependent Variable (Food loss percentage at Harvesting)**	
Independent variable	Coefficient (std. error)	Coefficient (std. error)
Agriculture value added share of GDP (t-1)	0.000 (0.000)	-
Agriculture value added share of GDP (t-2)	0.000 (0.000)	-
Agricultural share of government expenditure (t-1)	-	0.000 (0.000)
Agricultural share of government expenditure (t-2)	-	0.000 (0.000)
Year	Included	Included
Country	Included	Included
Basket Items Fruits and Veg	0.602* (0)	0.496* (0)
Basket Items Meat and Animal Products	-1.697* (0)	-1.294* (0)
Basket Items Roots, Tubers & Oil-Bearing Crops	-0.475* (0)	-0.121* (0)
Residual standard error	0	0
No. of observations	566	661

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 6 Results of panel regression analysis for hypothesis 1

PANEL REGRESSION	**Dependent Variable (Food loss percentage at Harvesting)**	
Independent variable	Coefficient (std. error)	Coefficient (std. error)
Agriculture value added share of GDP (t-1)	0.056 (0.097)	-
Agriculture value added share of GDP (t-2)	-0.035 (0.097)	-
Agricultural share of government expenditure (t-1)	-	-0.052 (0.046)
Agricultural share of government expenditure (t-2)	-	-0.043 (0.044)
Year	Included	Included
Country	Included	Included
Basket Items Category	Included	Included

R square	0.000	0.006
F value	0.170	1.905
No. of observations	566	661

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

5.2 Storage Stage (Hypothesis 2)

We conducted a multiple linear regression analysis to explore the relationship between the time required to build warehouses and food loss at the storage stage. The analysis involved a dataset consisting of 317 observations from various countries and years. The mean food loss percentage at the storage stage was approximately 4.04%, ranging from 0.60% to 45.00%. We used a linear regression model with log-transformed food loss percentage as the dependent variable and log-transformed time required to build warehouse values of the last two years as independent variables, the control variables of country, year and basket item remained the same. A coefficient estimate value of -0.164 was obtained for the variable log-transformed time required to build warehouse (t-1) which suggests an inverse relationship with log-transformed food loss percentage. However, a high p-value of 0.421 was observed which indicates that the relationship is not statistically significant and there may not be a meaningful association between the time required to build warehouses in the previous year and food loss percentage at the storage stage. However, a positive and statistically significant relationship was observed between the variable log-transformed time required to build warehouse (t-2) and log-transformed food loss percentage suggesting that an increase in time required to built warehouses two years ago resulted in an increase in the current food loss percentage at the storage stage. Although the p value was only 0.072, slightly above the conventional threshold of 0.05 and hence cannot be completely relied upon. The regression model had an overall good fit, with an R-squared value of 0.709 which means that 70.9% of the variance in log-transformed food loss percentage was explained by the independent variables.

The robust regression model had a coefficient value of 0 for the log-transformed time required to build warehouse (t-1) and (t-2) variable which indicates no linear relationship between it and log-transformed loss percentage at storage stage. However, associated t-values indicate that these coefficients are not statistically significant. The residual standard error value shows that the model fits the data well, but time required to build warehouse may not be a good independent variable to predict food loss at the storage stage.

The panel regression model yielded an estimate coefficient of -0.345 which was not significant ($p = 0.140$) for time required to build warehouse (t-1), indicating a non-significant relationship with food loss percentage. However, the coefficient estimate for time required to build warehouse (t-2) was 0.582 and was also significant indicating that an increase in the time required to build warehouse two years ago resulted in higher food loss percentage at the storage stage in the current year.

The coefficients for both lagged and panel regression for time required to build warehouse two years ago were positive and statistically significant indicating that an increase in the time required to build warehouse two years ago could result in an increased food loss percentage at the storage stage.

Based on the analysis carried out with the proxy for ‘development of storage infrastructure’ we can conclude that the results partially support our hypothesis that insufficient development of storage infrastructure increases food loss at the storage stage.

Table 7 Results of regression analysis for hypothesis 2

OLS REGRESSION	**Dependent Variable (Food loss percentage at Storage)**
Independent variable	Coefficient (std. error)
Time required to build a warehouse (days) (t-1)	-0.164 (0.204)
Time required to build a warehouse (days) (t-2)	0.366. (0.203)

Year	Included
Country	Included
Basket Items Fruits & Vegetables	0.786*** (0.161)
Basket Items Meat and Animal Products	0.411 (0.447)
Basket Items Roots, Tubers & Oil-Bearing Crops	0.966*** (0.129)
R square	0.710
F value	13.020
No. of observations	317

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 8 Results of robust regression analysis for hypothesis 2

ROBUST REGRESSION	**Dependent Variable (Food loss percentage at Storage)**
Independent variable	Coefficient (std. error)
Time required to build a warehouse (days) (t-1)	0.000 (0.000)
Time required to build a warehouse (days) (t-2)	0.000 (0.000)
Year	Included
Country	Included
Basket Items Fruits and Veg	1.052* (0.000)
Basket Items Meat and Animal Products	0.261* (0.000)
Basket Items Roots, Tubers & Oil-Bearing Crops	0.871* (0.000)
Residual standard error	0.000
No. of observations	317

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 9 Results of panel regression analysis for hypothesis 2

PANEL REGRESSION	**Dependent Variable (Food loss percentage at Storage)**
Independent variable	Coefficient (std. error)
Time required to build a warehouse (days) (t-1)	-0.345 (0.233)
Time required to build a warehouse (days) (t-2)	0.582* (0.232)

Year	Included
Country	Included
Basket Items Category	Included
R square	0.027
F value	3.596
No. of observations	317

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

5.3 Processing Stage (Hypothesis 3)

The relationship between industrial and technological infrastructure development, represented by Manufacturing, value added (% of GDP), and food loss at the processing stage was checked using multiple linear regression. The analysis was conducted using a dataset comprising 63 observations from various countries and years. The mean food loss percentage at the processing stage was approximately 5.81%, ranging from 0.01% to 32.86%. A significant negative coefficient was observed for Manufacturing, value added (% of GDP) (t-1) ($\beta = -5.825$, p-value < 0.001), indicating that a higher percentage of manufacturing value added as a proportion of GDP in the previous year was associated with lower food loss percentages at the processing stage in the current year. The coefficient for Manufacturing, value added (% of GDP) (t-2) was found to be 0.001 which indicates that an increase in the Manufacturing, value added (% of GDP) two years ago is associated with an increase in food loss in the current year at the processing stage. However, the p-value for this variable was 0.100 which indicated no significant association between Manufacturing, value added (% of GDP) value two years ago and the log-transformed food loss percentage. The regression model showed an R-squared value of 0.908, indicating that the model had a good fit and approximately 90.8% of the variance in food loss percentage at the processing stage was explained by the independent variables.

The robust regression model yielded a negative and significant coefficient for log of manufacturing, value added (% of GDP) (t-1) (-5.624, t = -19.995), indicating that a higher percentage of manufacturing value added as a proportion of GDP in the previous year was associated with lower food loss percentages at the processing stage. However, the coefficient for log of manufacturing, value added (% of GDP) (t-2) was positive and significant (0.856, t = 2.179) indicating an increase in manufacturing value added as a proportion of GDP two years ago, increased food loss percentage. The residual standard error of 0.086 highlights the overall accuracy of the model.

The panel regression model revealed a significant negative coefficient for log of manufacturing, value added (% of GDP) (t-1), -7.422 with a p-value of 0.006, suggesting that an increase in the value added in manufacturing in the previous year was associated with a decrease in food loss at the processing stage in the current year. The estimate for manufacturing, value added (% of GDP) (t-2) was positive however it was not significant with a p-value of 0.209.

The negative coefficient values for log of manufacturing, value added (% of GDP) in the previous year (t-1) along with significant p and t values suggest that the development of manufacturing infrastructure in the previous year plays a role in mitigating food loss at the processing stage in the current year. However, coefficient values for log of manufacturing, value added (% of GDP) in two years ago were positive and mostly insignificant indicating that this variable might not explain food loss at the processing stage.

Based on the analysis carried out with the proxy for 'development of processing infrastructure' we can conclude that the results partially support our hypothesis that insufficient development of processing infrastructure increases food loss at the processing stage.

Table 10 Results of regression analysis for hypothesis 3

OLS REGRESSION	**Dependent Variable (Food loss percentage at Processing)**
Independent variable	Coefficient (std. error)
Manufacturing, value added (% of GDP) (t-1)	-5.826*** (1.025)
Manufacturing, value added (% of GDP) (t-2)	0.001 (1.431)
Year	Included
Country	Included
Basket Items Fruits & Vegetables	1.104* (0.446)
Basket Items Meat and Animal Products	0.169 (0.632)
Basket Items Roots, Tubers & Oil-Bearing Crops	0.234 (0.306)
R square	0.909
F value	7.160
No. of observations	63

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 11 Results of robust regression for hypothesis 3

ROBUST REGRESSION	**Dependent Variable (Food loss percentage at Processing)**
Independent variable	Coefficient (std. error)
Manufacturing, value added (% of GDP) (t-1)	-5.624* (0.281)
Manufacturing, value added (% of GDP) (t-2)	0.856 (0.393)
Year	Included
Country	Included
Basket Items Fruits and Veg	1.393* (0.1223)
Basket Items Meat and Animal Products	0.368* (0.173)
Basket Items Roots, Tubers & Oil-Bearing Crops	0.238* (0.084)
Residual standard error	0.086
No. of observations	63

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 12 Results of panel regression analysis for hypothesis 3

PANEL REGRESSION	**Dependent Variable (Food loss percentage at Processing)**
Independent variable	Coefficient (std. error)
Manufacturing, value added (% of GDP) (t-1)	-7.422** (2.327)
Manufacturing, value added (% of GDP) (t-2)	6.149 (4.680)
Year	Included
Country	Included
Basket Items Category	Included
R square	0.405
F value	5.108
No. of observations	63

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

5.4 Transportation Stage (Hypothesis 4)

Transport infrastructure investment

We investigated the impact of transportation infrastructure development, represented by transport infrastructure investment, on food loss at the transportation stage. Utilizing a dataset comprising 18 observations from various countries and years, we conducted a multiple linear regression analysis. The independent variables were the logarithm of transport infrastructure investment values for the last two years, and the dependent variable was the percentage of food loss at the transportation stage. The linear regression model provided estimates for the coefficients of the independent variables. The coefficient for transport infrastructure investment (t-1) suggests a negative relationship with food loss percentage but it was not statistically significant ($\beta = -3.043$, $p = 0.817$). On the other hand, the coefficient for transport infrastructure investment (t-2) was positive, 9.215 indicating that an increase in transport infrastructure investment two years ago would increase the current food loss percentage. However, this coefficient was also not statistically significant (p-value = 0.292), indicating that there is no significant association between investment value two years ago and the loss percentage. This finding contradicts the initial hypothesis, indicating that the level of investment in transportation infrastructure may not directly influence food loss at the transportation stage. The R-squared value of 0.580 indicates that the model had an overall good fit and 58.0% variation in food loss percentage at the transportation stage could be explained by the independent variables.

For the robust regression, the coefficient of -0.968 was obtained for the logarithm of transport infrastructure investment (t-1) with a t-value of -0.076 and the coefficient of 10.422 was obtained for the logarithm of transport infrastructure investment (t-2) with a t-value of -1.269. The coefficient suggests that transport infrastructure investment in the previous year has a negative association with food loss whereas transport infrastructure two years ago has a positive association, but the t-values indicate that neither of these relationships are statistically significant.

The negative coefficient of -8.519 was observed for transportation infrastructure investment (t-1) but it was not statistically significant whereas a statistically significant positive coefficient value of 8.773 was obtained for transportation infrastructure investment (t-2) in the panel regression model suggesting a positive relationship with food loss percentage at the transportation stage.

Overall, all the three regressions showed positive but non-significant (except for panel regression) association between transportation infrastructure investment (t-2) and food loss at the transportation stage whereas negative yet non-significant values were obtained for transportation infrastructure investment (t-1) suggesting that insufficient transportation infrastructure investment may not directly influence food loss at the transportation stage.

Transport infrastructure maintenance

We investigated the relationship between transportation infrastructure maintenance and food loss at the transportation stage. The dataset comprised 17 observations across different countries and years. The multiple linear regression model provided the coefficient estimate for the transportation infrastructure maintenance (t-1) which was 0.004 with a p value of 0.033. This suggests a very small positive and statistically significant association with food loss at the transportation stage. Also, the variable transportation infrastructure maintenance (t-2) has an extremely small yet significant negative coefficient of -0.005 indicating that an investment in transportation infrastructure maintenance two years ago would marginally reduce the current food loss percentage at the transportation stage. The R-squared value of 0.785 indicates that the model has an overall good fit.

For the robust regression model, a coefficient value of 0.004 and -0.004 was obtained for transport infrastructure maintenance (t-1) and (t-2) respectively with significant t-values for both variables suggesting that an increase in transportation infrastructure maintenance one year ago would increase the food loss whereas an increase in transportation infrastructure maintenance two years ago would decrease the food loss at the transportation stage. Additionally, a residual standard error of 0.371, indicates that the model has a good accuracy.

The panel regression model was employed, and the analysis revealed a positive and negative coefficient value of 0.004 and -0.003 for variables transportation infrastructure maintenance (t-1) and (t-2) respectively, corroborating the same findings as that of the lagged regression and robust regression. Although as the p-values are very big, these results are not statistically significant.

Overall, negative coefficient values for transportation infrastructure maintenance (t-2) were obtained in the lagged, robust and panel regression results, but the result for panel regression was not statistically significant and hence we cannot conclude that an increase in transport maintenance expenditure decreases food loss at the transportation stage.

Based on the analysis carried out with both the proxies for ‘development of transportation infrastructure’ we can conclude that the results do not support our hypothesis that insufficient development of transportation infrastructure increases food loss at the transportation stage.

Given the inconclusive findings and the limited scope of the dataset, further research with a larger and more diverse sample is recommended to better understand the relationship between transportation infrastructure investment and maintenance with food loss at the transportation stage. Additionally, qualitative investigations into the specific mechanisms underlying food loss during transportation could provide valuable insights complementary to quantitative analyses.

Table 13 Results of regression analysis for hypothesis 4

OLS REGRESSION	**Dependent Variable (Food loss percentage at Transportation)**	
Independent variable	Coefficient (std. error)	Coefficient (std. error)
Transport infrastructure investment (t-1)	-3.043 (12.691)	-
Transport infrastructure investment (t-2)	9.215 (8.172)	-
Transport infrastructure maintenance (t-1)	-	0.004* (0.002)
Transport infrastructure maintenance (t-2)	-	-0.005** (0.001)
Year	Included	Included
Country	Included	Included
Basket Items Fruits & Vegetables	2.504 (2.636)	5.275* (1.744)
Basket Items Meat and Animal Products	-0.317 (3.180)	1.447 (2.271)
Basket Items Roots, Tubers & Oil-Bearing Crops	-0.487 (2.759)	1.763 (1.913)
R square	0.580	0.785
F value	1.226	3.658

No. of observations	18	17

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 14 Results of robust regression analysis for hypothesis 4

ROBUST REGRESSION	**Dependent Variable (Food loss percentage at Transportation)**	
Independent variable	Coefficient (std. error)	Coefficient (std. error)
Transport infrastructure investment (t-1)	-0.968 (12.759)	-
Transport infrastructure investment (t-2)	10.422 (8.215)	-
Transport infrastructure maintenance (t-1)	-	0.004* (0.001)
Transport infrastructure maintenance (t-2)	-	-0.004* (0.000)
Year	Included	Included
Country	Included	Included
Basket Items Fruits and Veg	1.516 (2.650)	6.306* (0.596)
Basket Items Meat and Animal Products	-0.454 (3.198)	0.599 (0.776)
Basket Items Roots, Tubers & Oil-Bearing Crops	-0.771 (2.773)	0.434 (0.653)
Residual standard error	1.812	0.372
No. of observations	18	17

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 15 Results of panel regression analysis for hypothesis 4

PANEL REGRESSION	**Dependent Variable (Food loss percentage at Transportation)**	
Independent variable	Coefficient (std. error)	Coefficient (std. error)
Transport infrastructure investment (t-1)	-8.519 (5.086)	-
Transport infrastructure investment (t-2)	8.773* (3.963)	-
Transport infrastructure maintenance (t-1)	-	0.004 (0.002)
Transport infrastructure maintenance (t-2)	-	-0.003 (0.002)
Year	Included	Included
Country	Included	Included
Basket Items category	Included	Included
R square	0.337	0.208

F value	3.049	1.573
No. of observations	18	17

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

6 DISCUSSION

Our research is an analysis of different country level factors and food loss at different stages of the agricultural value chain. Through meticulous analysis, we scrutinized the impacts of agricultural infrastructure development, storage infrastructure development, industrial and technological infrastructure development and transportation infrastructure investment and maintenance in the preceding two years on food loss at various stages of the food supply chain.

Examining the relationship between agricultural infrastructure development (t-1) and (t-2) with food loss at the harvesting stage, none of the proxies used, agriculture value added share of GDP or agriculture share of government expenditure showed statistical significance in their relationship with food loss at the harvesting stage. Similarly, for storage stage, a statistically significant association did not emerge between our independent variable, time required to build a warehouse (t-1) and the dependent variable, food loss at the storage stage. However, OLS and panel regression showed a statistically positive association between time required to build a warehouse (t-2) and food loss percentage suggesting that an increase in the time required to build warehoused two years ago affected food loss at the storage stage.

The analysis between the independent variable for the processing stage; manufacturing value added (% of GDP) (t-1) yielded negative and significant results whereas for manufacturing value added (% of GDP) (t-2), positive and non-statistically significant results were observed. This suggests that an increase in the Manufacturing value added (% of GDP) in the previous year causes a decrease in the food loss percentage at the processing stage in the present year. This highlights the impact of manufacturing infrastructure development and sheds light on potential avenues for enhancing food security through targeted investments and policy interventions.

The analysis of transportation infrastructure development on food loss during transportation revealed statistically insignificant results for both (t-1) and (t-2) and although statistically significant results were observed for transport infrastructure maintenance (t-2) in OLS and well as robust regression analysis, the values were close to zero, indicating no effect on food loss This could be due to the small sample size for both of these analyses. This unexpected finding highlights the need for more extensive research into the multifaceted factors influencing food loss during transportation. While investments in transportation infrastructure are crucial for ensuring efficient food distribution, our findings suggest that other factors beyond infrastructure alone may play significant roles in determining food loss outcomes during transportation.

Through statistical analysis, our study contributes to a deeper understanding of the complex dynamics shaping food loss across the agricultural supply chain. Although the findings were inconclusive, it could be due to various reasons as will be discussed further but studying such country level factors can offer valuable insights for policymakers, practitioners, and stakeholders in designing targeted interventions to mitigate food loss and enhance food security globally.

7 LIMITATIONS AND CONCLUSION

While our study provides valuable insights into the relationship between infrastructure development and food loss across different stages of the agricultural value chain, several limitations should be acknowledged. Firstly, the reliance on secondary data sources may introduce measurement error and limit the comprehensiveness of our analysis. FAO highlights that national estimates often underestimate the extent of food loss presenting lower bounds of the data and data comparison is a challenge due to diverse measurement methodologies across regions and products, and inconsistent data over time. There are biases and variabilities in the collected data, both nationally and within studies underscoring the need for precise and reliable measurement methods. Moreover, significant data gaps exist by country, commodity, and throughout the supply chain, filled by modeled estimates that may not reflect true food loss percentages accurately. Additionally, the relatively small sample sizes in some analyses may impact the results as small samples for regression analysis can cause increased variability in results and reduce the statistical power of the models used. Furthermore, some of the variables used in our analysis like Agriculture value added share of GDP, Time required to build a warehouse and Manufacturing, value added (% of GDP) do not fully represent their constructs of development at harvesting, storage and processing stage but are an indirect measure.

Lastly, our research focuses only on quantitative analysis overlooking the qualitative aspects that could provide a deeper understanding of the mechanisms underlying food loss. To address these limitations, future research endeavours could incorporate larger and more diverse datasets and integrate qualitative methodologies to capture contextual nuances. Additionally, employing advanced statistical techniques such as structural equation modelling or machine learning algorithms may offer deeper insights into the complex interactions between infrastructural factors and food loss outcomes.

In conclusion, our study illuminates the intricate relationships between country level factors and food loss across diverse stages of the agricultural supply chain. While our study aims to contribute to a better understanding of the factors shaping food loss, it is necessary to recognize the inherent limitations of our analysis. Moving forward, addressing these limitations, and adopting a multifaceted approach consisting of quantitative and qualitative methodologies will be crucial in advancing our understanding of food loss at various stages of the supply chain and developing strategies to enhance food security globally.

8 REFERENCES

Abdulla, M., Martin, R., Gooch, M., & Jovel, E. (2013). The importance of quantifying food waste in Canada. Journal of Agriculture, Food Systems, and Community Development, 3(2), 137-151.

Abiad, M. G., & Meho, L. I. (2018). Food loss and food waste research in the Arab world: A systematic review. Food security, 10, 311-322.

Ahmed, J. U., Akter, S., & Majumder, K. A. (2021). Impact of COVID-19 on agricultural production and distribution in South Asia. World Food Policy, 7(2), 168-182.

Alexander, P., Brown, C., Arneth, A., Finnigan, J., Moran, D., & Rounsevell, M. D. (2017). Losses, inefficiencies and waste in the global food system. Agricultural systems, 153, 190-200.

Ali, S. M., Moktadir, M. A., Kabir, G., Chakma, J., Rumi, M. J. U., & Islam, M. T. (2019). Framework for evaluating risks in food supply chain: Implications in food wastage reduction. Journal of cleaner production, 228, 786-800.

Amicarelli, V., & Bux, C. (2021). Food waste in Italian households during the Covid-19 pandemic: a self-reporting approach. Food Security, 13(1), 25-37.

Aragie, E., Balié, J., & MoralesOpazo, C. (2018). Does reducing food losses and wastes in sub-Saharan Africa make economic sense?. Waste Management & Research, 36(6), 483-494.

Wastage, A. F. More Responsible Food Consumption.

Azatbek, T., Raimbekov, Z., & Syzdykbayeva, B. (2021). Cluster analysis of agricultural products storage infrastructure in Kazakhstan: directions and development prospects. Problems of AgriMarket, (3), 124-133.

Beausang, C., Hall, C., & Toma, L. (2017). Food waste and losses in primary production: Qualitative insights from horticulture. Resources, Conservation and Recycling, 126, 177-185.

Beretta, C., Stoessel, F., Baier, U., & Hellweg, S. (2013). Quantifying food losses and the potential for reduction in Switzerland. Waste management, 33(3), 764-773.

Bilska, B., Wrzosek, M., Kołożyn-Krajewska, D., & Krajewski, K. (2016). Risk of food losses and potential of food recovery for social purposes. Waste Management, 52, 269-277.

Bond, M., Meacham, T., Bhunnoo, R., & Benton, T. (2013). Food waste within global food systems. Swindon, UK: Global Food Security.

Bowman, M., O'Sullivan, C. 2018. Farmers talk food waste: Supermarkets' role in crop waste on UK farms.

Brancoli, P., Lundin, M., Bolton, K., & Eriksson, M. (2019). Bread loss rates at the supplier-retailer interface–Analysis of risk factors to support waste prevention measures. Resources, Conservation and Recycling, 147, 128-136.

Rojas-Vargas, J., Monge-Fernández, Y., Jiménez-Morales, M. F., Brenes-Peralta, L., Arguedas-Camacho, M., Hidalgo-Viquez, C., ... & Vásquez-Rodríguez, B. (2021). Food loss and waste in food services from educational institutions in Costa Rica. Revista Tecnología en Marcha, 34(2), 187-196.

Buzby, J. C., & Hyman, J. (2012). Total and per capita value of food loss in the United States. Food policy, 37(5), 561-570.

Cardoen, D., Joshi, P., Diels, L., Sarma, P. M., & Pant, D. (2015). Agriculture biomass in India: Part 2. Post-harvest losses, cost and environmental impacts. Resources, Conservation and Recycling, 101, 143-153.

Chaminuka, P., Senyolo, G. M., Makhura, M. N., & Belete, A. (2008). A factor analysis of access to and use of service infrastructure amongst emerging farmers in South Africa. Agrekon, 47(3), 365-378.

Chauhan, C., Dhir, A., Akram, M. U., & Salo, J. (2021). Food loss and waste in food supply chains. A systematic literature review and framework development approach. Journal of Cleaner Production, 295, 126438.

Chekunov, A. S. (2019). Technological modernization of agricultural production: condition, forms, methods and directions of innovations support.

Chen, X., Wu, L., Shan, L., & Zang, Q. (2018). Main factors affecting post-harvest grain loss during the sales process: a survey in nine provinces of China. Sustainability, 10(3), 661.

Corrado, S., Ardente, F., Sala, S., & Saouter, E. (2017). Modelling of food loss within life cycle assessment: From current practice towards a systematisation. Journal of cleaner production, 140, 847-859.

Delgado, L., Schuster, M., & Torero, M. (2021). Quantity and quality food losses across the value chain: a comparative analysis. Food Policy, 98, 101958.

Devin, B., & Richards, C. (2018). Food waste, power, and corporate social responsibility in the Australian food supply chain. Journal of Business Ethics, 150, 199-210.

Doliente, S. S., & Samsatli, S. (2021). Integrated production of food, energy, fuels and chemicals from rice crops: multi-objective optimisation for efficient and sustainable value chains. Journal of cleaner production, 285, 124900.

Dora, M., Wesana, J., Gellynck, X., Seth, N., Dey, B., & De Steur, H. (2020). Importance of sustainable operations in food loss: Evidence from the Belgian food processing industry. Annals of operations research, 290, 47-72.

Kojo, R., Nchege, J., & Dorathy, I. (2020). Infrastructure Development, Capacity Utilization and Manufacturing Value Added in Nigeria. Economics, 7(2), 104-111.

Engström, R., & Carlsson-Kanyama, A. (2004). Food losses in food service institutions Examples from Sweden. Food policy, 29(3), 203-213.

FAO. Impacts on Natural Resources. FAO; Rome, Italy: 2013. Food wastage footprint. Summary Report.

Folkerts, H., & Koehorst, H. (1998). Challenges in international food supply chains: vertical co-ordination in the European agribusiness and food industries. British Food Journal, 100(8), 385-388.

GEP. (2023) https://www.gep.com/blog/strategy/food-supply-chain-stages-models-challenges-best-practices

Geylani, P. C., & Stefanou, S. E. (2013). Linking investment spikes and productivity growth. Empirical Economics, 45, 157-178.

Girotto, F., Alibardi, L., & Cossu, R. (2015). Food waste generation and industrial uses: A review. Waste management, 45, 32-41.

Göbel, C., Langen, N., Blumenthal, A., Teitscheid, P., & Ritter, G. (2015). Cutting food waste through cooperation along the food supply chain. Sustainability, 7(2), 1429-1445.

Gustafsson, J., Cederberg, C., Sonesson, U., & Emanuelsson, A. (2013). The methodology of the FAO study: Global Food Losses and Food Waste-extent, causes and prevention"-FAO, 2011.

Gustavsson, J., & Stage, J. (2011). Retail waste of horticultural products in Sweden. Resources, Conservation and Recycling, 55(5), 554-556.

Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R., & Meybeck, A. (2011). Global food losses and food waste.

Halloran, A., Clement, J., Kornum, N., Bucatariu, C., & Magid, J. (2014). Addressing food waste reduction in Denmark. Food policy, 49, 294-301.

Hardman, C. A., Ferriday, D., Kyle, L., Rogers, P. J., & Brunstrom, J. M. (2015). So many brands and varieties to choose from: does this compromise the control of food intake in humans? PLoS One, 10(4), e0125869.

Hartikainen, H., Mogensen, L., Svanes, E., & Franke, U. (2018). Food waste quantification in primary production–the Nordic countries as a case study. Waste Management, 71, 502-511.

HLPE. Food Losses and Waste in the Context of Sustainable Food Systems. A Report by the High-Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security; Committee on World Food Security: Rome, Italy, 2014.

Hodges, R. J., Buzby, J. C., & Bennett, B. (2011). Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. The Journal of Agricultural Science, 149(S1), 37-45.

Hunter, M. C., Smith, R. G., Schipanski, M. E., Atwood, L. W., & Mortensen, D. A. (2017). Agriculture in 2050: recalibrating targets for sustainable intensification. Bioscience, 67(4), 386-391.

ITLN-Indian Transport and Logistics News, 2014. India on Fast Track to Shape Perishables Logistics Trends.

Jagtap, S., Trollman, H., Trollman, F., Garcia-Garcia, G., Parra-López, C., Duong, L., ... & Afy-Shararah, M. (2022). The Russia-Ukraine conflict: Its implications for the global food supply chains. Foods, 11(14), 2098.

Jain, N. (2007). International Conference on Agribusiness and Food Industry in Developing Countries: Opportunities and Challenges.

Janssen, S., Pankoke, I., Klus, K., Schmitt, K., Stephan, U., & Wöllenstein, J. (2014). Two underestimated threats in food transportation: Mould and acceleration. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 372(2017), 20130312.

Jeswani, H. K., Figueroa-Torres, G., & Azapagic, A. (2021). The extent of food waste generation in the UK and its environmental impacts. Sustainable Production and Consumption, 26, 532-547.

Jiang, S., Chen, H., Yang, S., Wang, Y., & Xu, M. (2023). Assessment and scenario hypothesis of food waste in China based on material flow analysis. npj Urban Sustainability, 3(1), 2.

Johnson, L. K., Bloom, J. D., Dunning, R. D., Gunter, C. C., Boyette, M. D., & Creamer, N. G. (2019). Farmer harvest decisions and vegetable loss in primary production. Agricultural systems, 176, 102672.

Kanani, R. (2019). Dealing with quality uncertainty in the supply chains of perishable agricultural produce: consideration of buyer-supplier geographical distance and the choice of procurement channel. International Journal of Management Concepts and Philosophy, 12(1), 55-79.

Kantor, L. S., Lipton, K., Manchester, A., & Oliveira, V. (1997). Estimating and addressing America's food losses. Food Review/National Food Review, 20(1), 2-12.

Karwowska, M., Łaba, S., & Szczepański, K. (2021). Food loss and waste in meat sector—why the consumption stage generates the most losses? Sustainability, 13(11), 6227.

Kazancoglu, Y., Ozkan-Ozen, Y. D., & Ozbiltekin, M. (2018). Minimizing losses in milk supply chain with sustainability: An example from an emerging economy. Resources, Conservation and Recycling, 139, 270-279.

Khawar, S., Suleman, R., Akhtar, S., Riaz, M., Ismail, T., Ismail, A., & Hameed, A. (2021). IMPACT OF VIRAL OUTBREAK COVID-19 ON FOOD SECURITY AND RELATED ECONOMIC CONSEQUENCES. Agricultural Sciences Journal, 3(2), 13-25.

Kiaya, V. (2014). Post-harvest losses and strategies to reduce them. Technical Paper on Postharvest Losses, Action Contre la Faim (ACF), 25, 1-25.

Koizumi, T. (2018). The contribution of agricultural investments to food loss and the world rice market in Asian countries. Japan Agricultural Research Quarterly: JARQ, 52(3), 181-196.

Kotykova, O., & Babych, M. (2019). Limitations in availability of food in Ukraine as a result of loss and waste. Oeconomia Copernicana, 10(1), 153-172.

Krzynowek, L., & Hawkins, J. (2015). Potato Waste Mapping for the" Bioenergy Potential from waste potatoes" project. Scottish Biofuel Programme, Napier University, Edinburgh.

Kumar, C., Ram, C. L., Jha, S. N., & Vishwakarma, R. K. (2021). Warehouse storage management of wheat and their role in food security. Frontiers in Sustainable Food Systems, 5, 675626.

Kumar, D., & Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods, 6(1), 8.

Li, D. China and global agricultural policy forum and launch of China agricultural industry development report 2019 and global food policy report 2019 in Beijing. World Agri. 6, 2–3 (2019).

Li, Z., & Thomas, C. (2014). Quantitative evaluation of mechanical damage to fresh fruits. Trends in Food Science & Technology, 35(2), 138-150.

Liang, L. (1993). China's post-harvest grain losses and the means of their reduction and elimination. Jingji dili (Econ. Geogr.), 1, 92-96.

Lipinski, B., Hanson, C., Waite, R., Searchinger, T., & Lomax, J. (2013). Reducing food loss and waste.

Liu, C., Jiang, H., Badulescu, D., & Bac, D. P. (2022). Achieving zero hunger goal through minimizing waste in food supply chain: evidence from Asian emerging region. Sustainability, 14(10), 5930.

Liu, J., Lundqvist, J., Weinberg, J., & Gustafsson, J. (2013). Food losses and waste in China and their implication for water and land. Environmental science & technology, 47(18), 10137-10144.

Lundqvist, J., De Fraiture, C., & Molden, D. (2008). Saving water: from field to fork: curbing losses and wastage in the food chain.

Magalhaes, V. S., Ferreira, L. M. D., & Silva, C. (2021). Causes and mitigation strategies of food loss and waste: a systematic literature review and framework development. Sustainable Production and Consumption, 28, 1580-1599.

Maheshwar, C., & Chanakwa, T. (2006, August). Postharvest losses due to gaps in cold chain in India-a solution. In IV International Conference on Managing Quality in Chains-The Integrated View on Fruits and Vegetables Quality 712 (pp. 777-784).

Matzembacher, D. E., Vieira, L. M., & de Barcellos, M. D. (2021). An analysis of multi-stakeholder initiatives to reduce food loss and waste in an emerging country–Brazil. Industrial Marketing Management, 93, 591-604.

Mena, C., & Whitehead, P. (2008). Evidence on the role of supplier-retailer trading relationships and practices in waste generation in the food chain.

Mena, C., Adenso-Diaz, B., & Yurt, O. (2011). The causes of food waste in the supplier–retailer interface: Evidences from the UK and Spain. Resources, Conservation and Recycling, 55(6), 648-658.

Mena, C., Terry, L. A., Williams, A., & Ellram, L. (2014). Causes of waste across multi-tier supply networks: Cases in the UK food sector. International Journal of Production Economics, 152, 144-158.

MOFPI − Ministry of Food Processing Industries, Government of India, S., 2014. Fruits & Vegetables, Retrieved from http://foodprocessingindia.co.in/fruits-and-vegetables.html. (accessed 17.12.15).

Murthy, D. S., Gajanana, T. M., Sudha, M., & Dakshinamoorthy, V. (2009). Marketing and post-harvest losses in fruits: its implications on availability and economy. Indian Journal of Agricultural Economics, 64(2).

Nicastro, R., & Carillo, P. (2021). Food loss and waste prevention strategies from farm to fork. Sustainability, 13(10), 5443.

Otten, J. J., Diedrich, S., Getts, K., & Benson, C. (2018). Commercial and anti-hunger sector views on local government strategies for helping to manage food waste. Journal of Agriculture, Food Systems, and Community Development, 8(B), 55-72.

Papargyropoulou, E., Lozano, R., Steinberger, J. K., Wright, N., & bin Ujang, Z. (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. Journal of cleaner production, 76, 106-115.

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. Philosophical transactions of the royal society B: biological sciences, 365(1554), 3065-3081.

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. Philosophical transactions of the royal society B: biological sciences, 365(1554), 3065-3081.

Porter, S. D., Reay, D. S., Bomberg, E., & Higgins, P. (2018). Avoidable food losses and associated production-phase greenhouse gas emissions arising from application of cosmetic standards to fresh fruit and vegetables in Europe and the UK. Journal of Cleaner Production, 201, 869-878.

Porter, S. D., Reay, D. S., Higgins, P., & Bomberg, E. (2016). A half-century of production-phase greenhouse gas emissions from food loss & waste in the global food supply chain. Science of the Total Environment, 571, 721-729.

Priefer, C., Jörissen, J., & Bräutigam, K. R. (2016). Food waste prevention in Europe–A cause-driven approach to identify the most relevant leverage points for action. Resources, Conservation and Recycling, 109, 155-165.

Raak, N., Symmank, C., Zahn, S., Aschemann-Witzel, J., & Rohm, H. (2017). Processing- and product-related causes for food waste and implications for the food supply chain. Waste management, 61, 461-472.

Redlingshöfer, B., Coudurier, B., & Georget, M. (2017). Quantifying food loss during primary production and processing in France. Journal of Cleaner Production, 164, 703-714.

Singh, A., Shukla, N., & Mishra, N. (2018). Social media data analytics to improve supply chain management in food industries. Transportation Research Part E: Logistics and Transportation Review, 114, 398-415.

Sobhani, S. R., & Babashahi, M. (2020). Determinants of household food basket composition: A systematic review. Iranian Journal of Public Health, 49(10), 1827.

Stuart, T. (2009). Waste: Uncovering the global food scandal. WW Norton & Company.

Fedorovich, S. V., Karimovna, S. G., Takhirovna, S. G., & Azimovna, S. S. (2019). Infrastructural development of agricultural products in the Republic of Kazakhstan. Экономика региона, 15(2), 561-575.

Times of India, 2014. 17 More Food Parks Planned to Counter Rs 44,000 Crore Wastage

Tostivint, C., de Veron, S., Jan, O., Lanctuit, H., Hutton, Z. V., & Loubière, M. (2017). Measuring food waste in a dairy supply chain in Pakistan. Journal of Cleaner Production, 145, 221-231.

Urutyan, V., & Yeritsyan, A. IAMO International Conference.

Veena, A., Babu, K. N., & Venkatesha, H. R. (2011). Supply Chain: A Differentiator in Marketing Fresh Produce. IUP Journal of Supply Chain Management, 8(1).

Verma, A., & Singh, K. P. (2004). An economic analysis of post-harvest losses in fresh vegetables. Indian Journal of Agricultural Marketing, 18(1), 136-139.

Viswanadham, N. (2006). Can India be the food basket for the world. Achieving rural and global supply chain excellence: the Indian way. Hyderabad: GLAMS, 1, 1-16.

Vittuari, M., De Menna, F., & Pagani, M. (2016). The hidden burden of food waste: the double energy waste in Italy. Energies, 9(8), 660.

Wang, J., Konar, M., Baylis, K., Estes, L., Hadunka, P., Xiong, S., & Caylor, K. (2023). Potential impacts of transportation infrastructure improvements to maize and cassava supply chains in Zambia. Environmental Research: Infrastructure and Sustainability, 3(4), 045006.

Willersinn, C., Mack, G., Mouron, P., Keiser, A., & Siegrist, M. (2015). Quantity and quality of food losses along the Swiss potato supply chain: Stepwise investigation and the influence of quality standards on losses. Waste management, 46, 120-132.

WRAP 2015. Strategies to achieve economic and environmental gains by reducing food waste. The Waste and Resources Action Programme.

WRAP, 2010. Waste Arisings in the Supply of Food and Drink to Households in the UK. Banbury, UK.

Wunderlich, S. M., & Martinez, N. M. (2018). Conserving natural resources through food loss reduction: Production and consumption stages of the food supply chain. International Soil and Water Conservation Research, 6(4), 331-339.

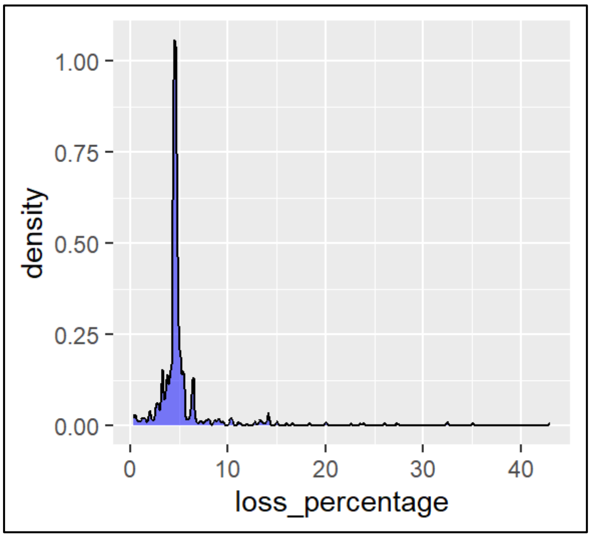
APPENDIX

HYPOTHESIS 1

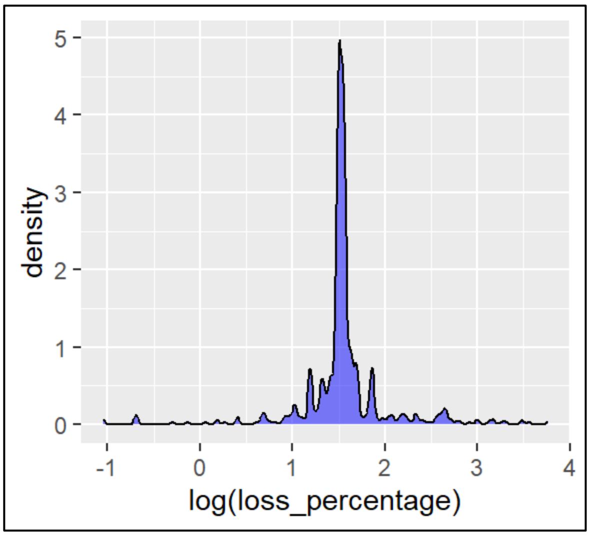
a)

Food loss percentage at harvesting stage

Before transformation

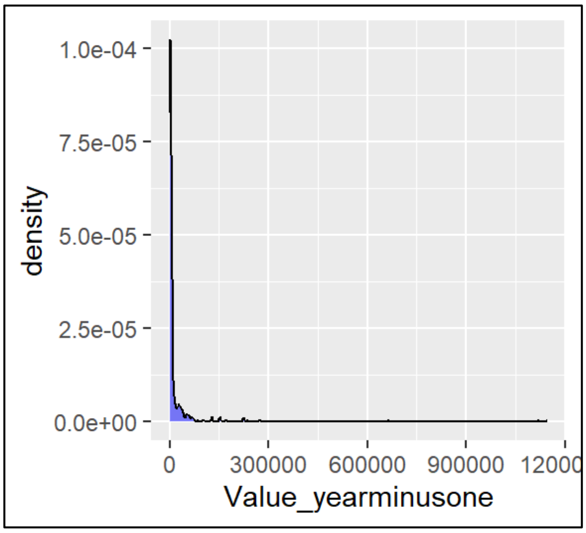


After transformation

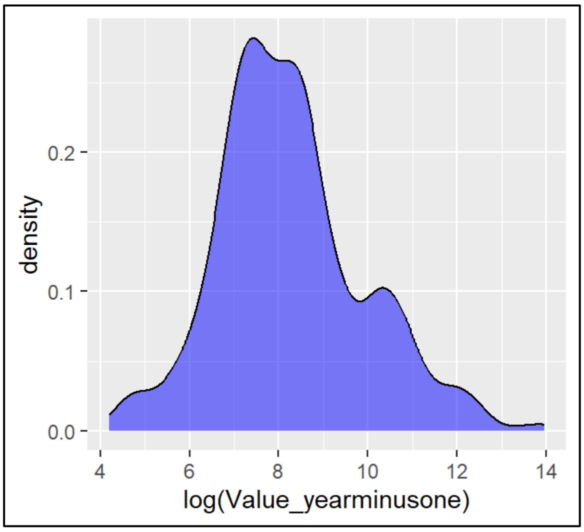


Agriculture value added share of GDP (t-1)

Before transformation

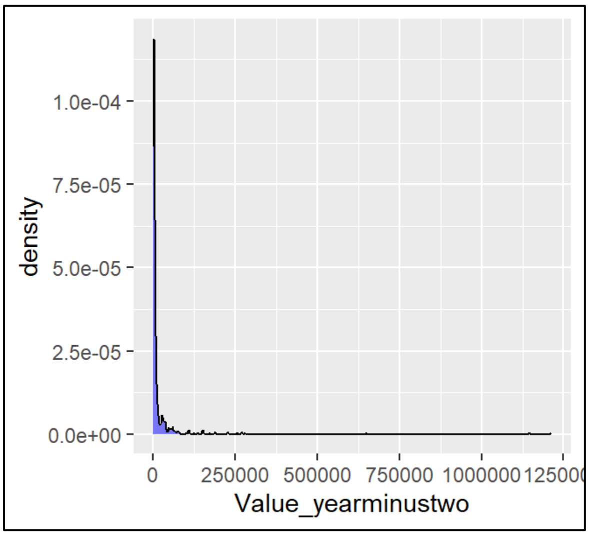


After transformation

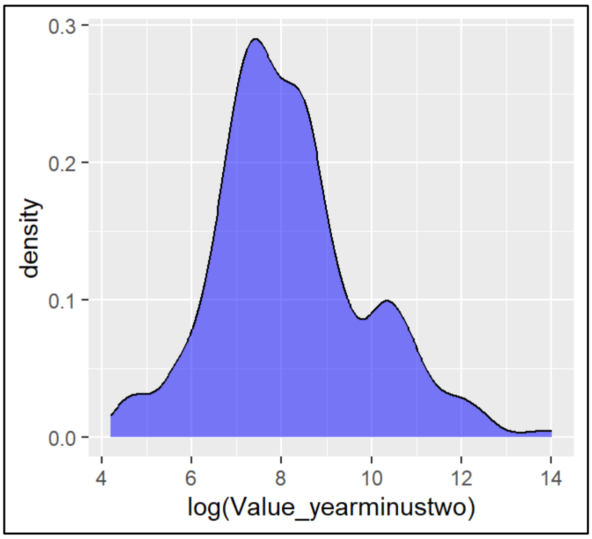


Agriculture value added share of GDP (t-2)

Before transformation



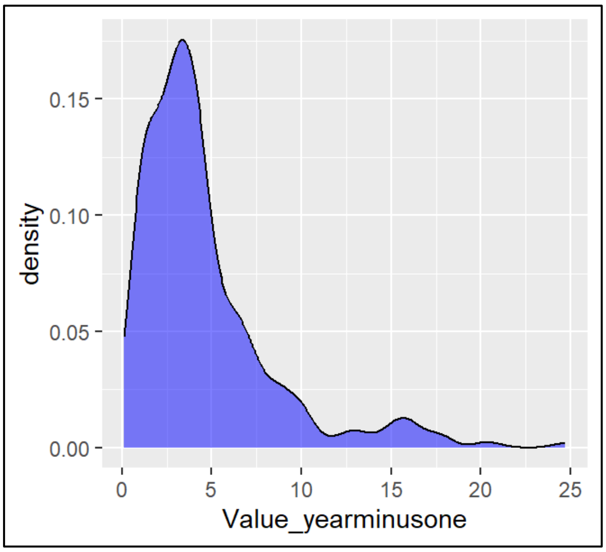
After transformation



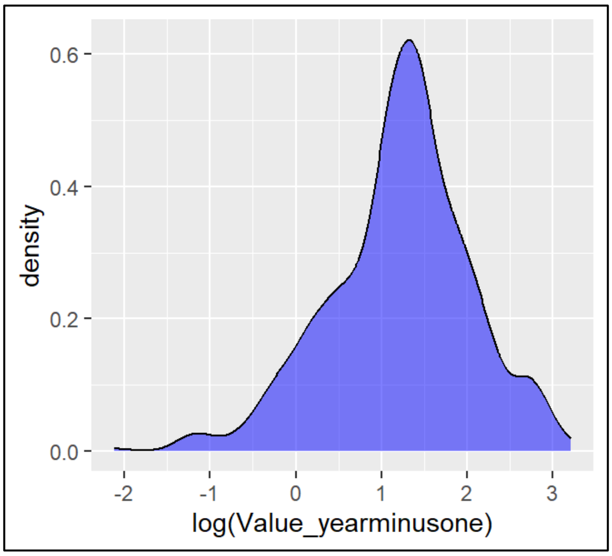
b)

Agricultural share of government expenditure (t-1)

Before transformation

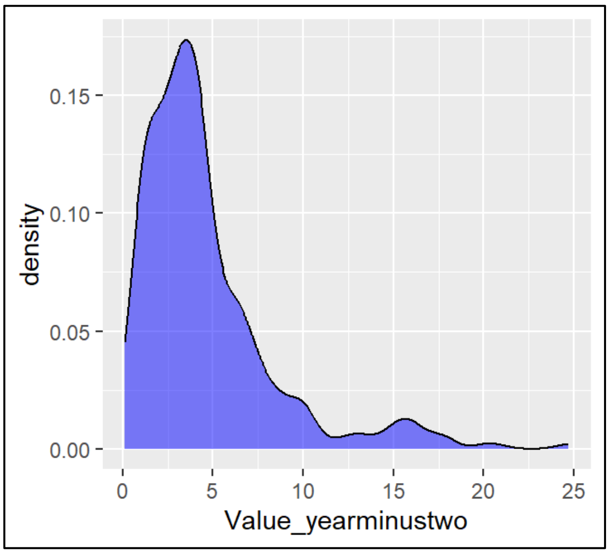


After transformation

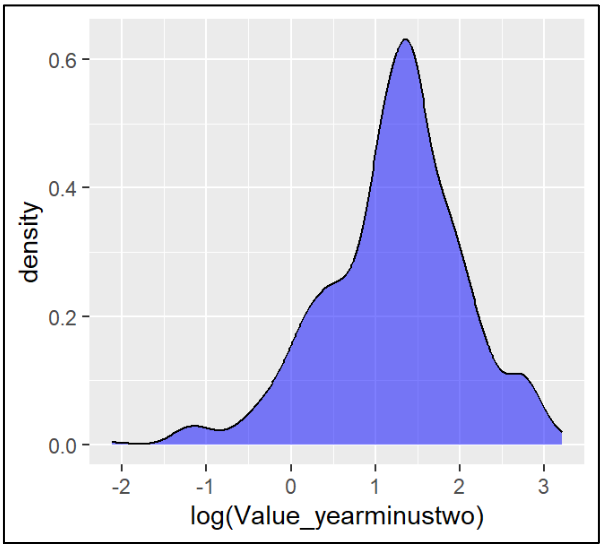


Agricultural share of government expenditure (t-2)

Before transformation



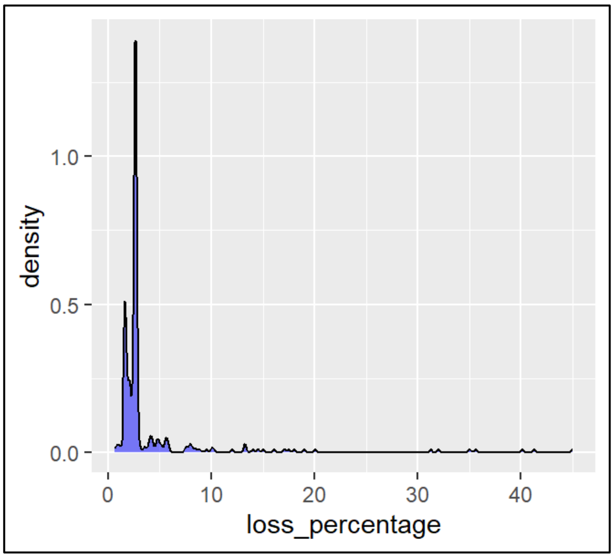
After transformation



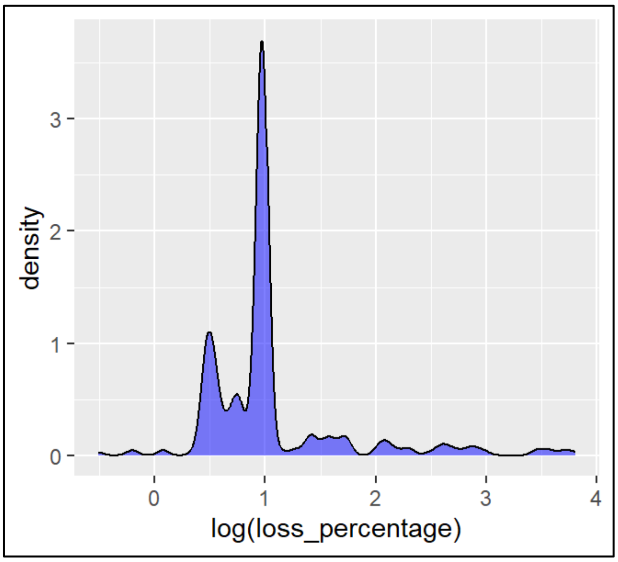
HYPOTHESIS 2

Food loss percentage at storage stage

Before transformation

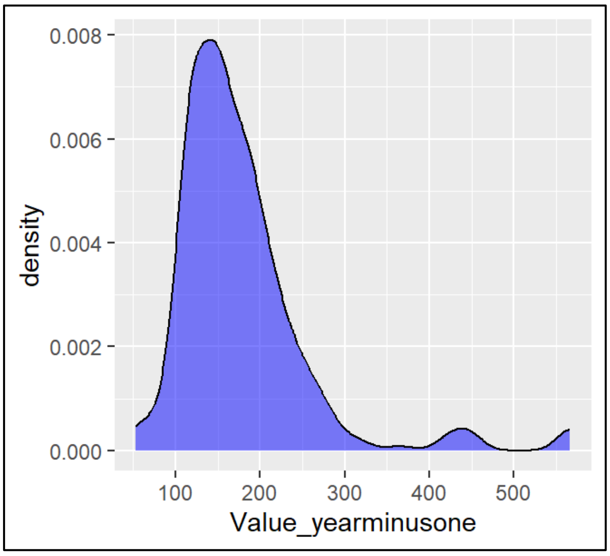


After transformation

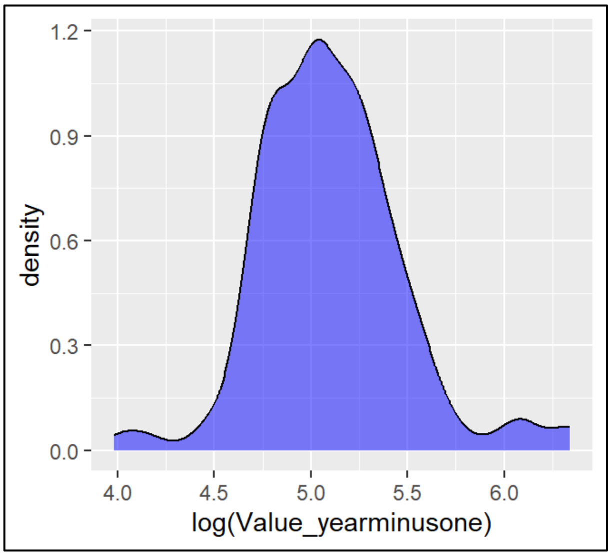


Time required to build a warehouse (days) (t-1)

Before transformation

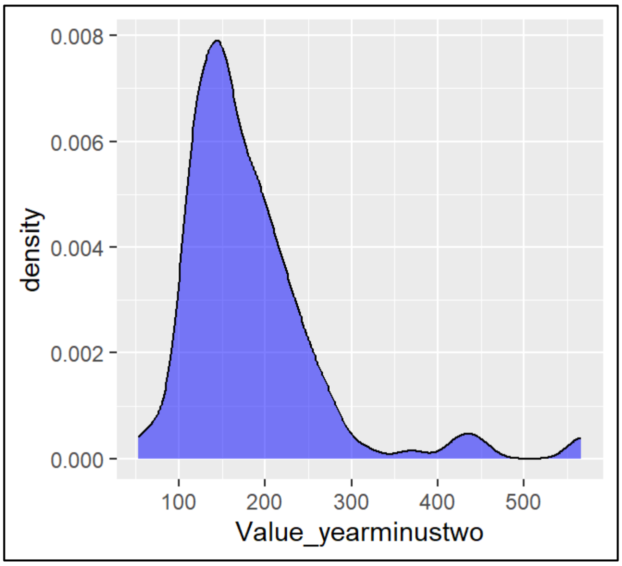


After transformation

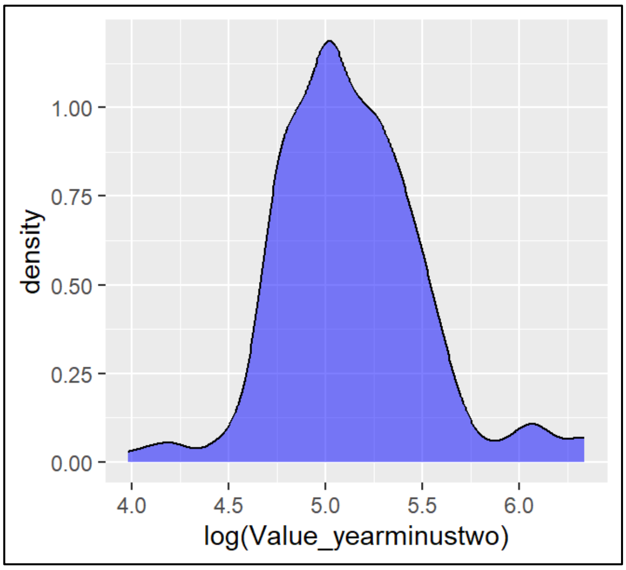


Time required to build a warehouse (days) (t-2)

Before transformation



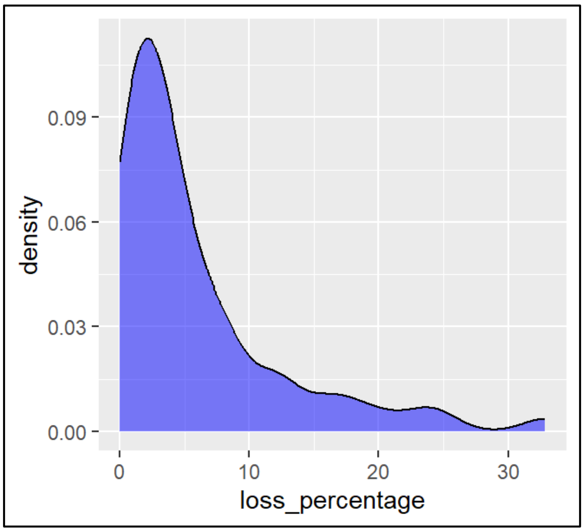
After transformation



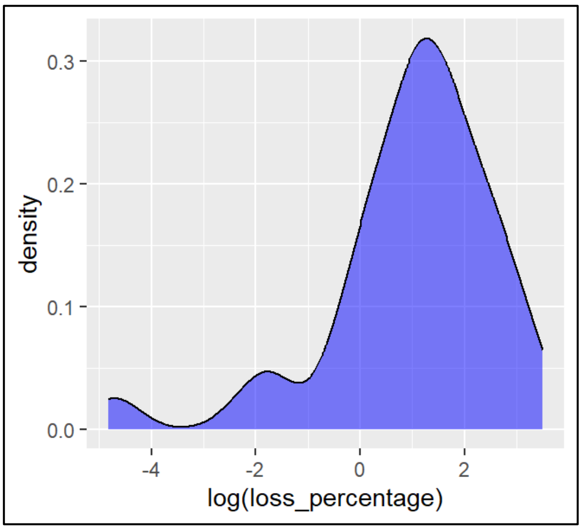
HYPOTHESIS 3

Food loss percentage at processing stage

Before transformation

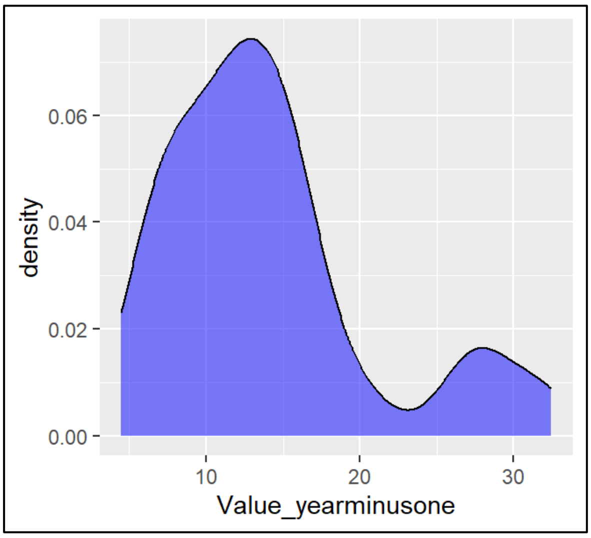


After transformation

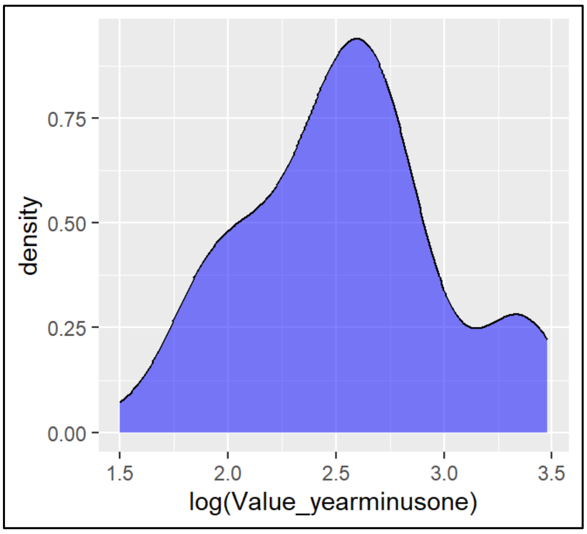


Manufacturing, value added (% of GDP) (t-1)

Before transformation

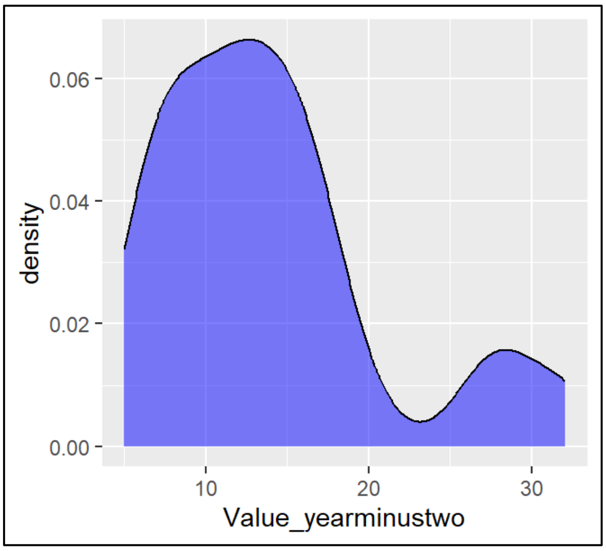


After transformation

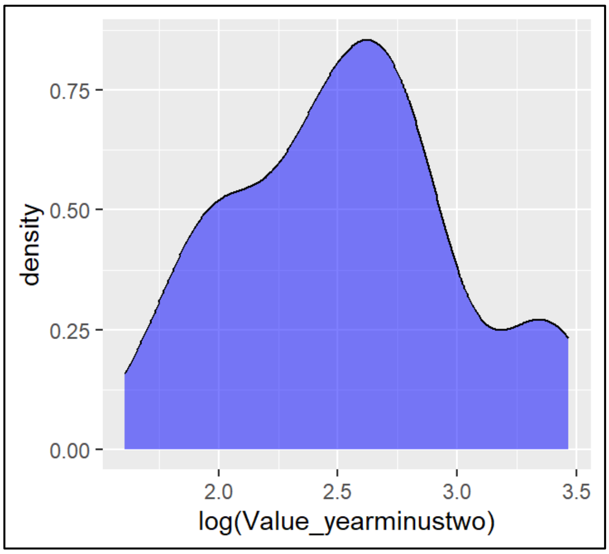


Manufacturing, value added (% of GDP) (t-2)

Before transformation



After transformation

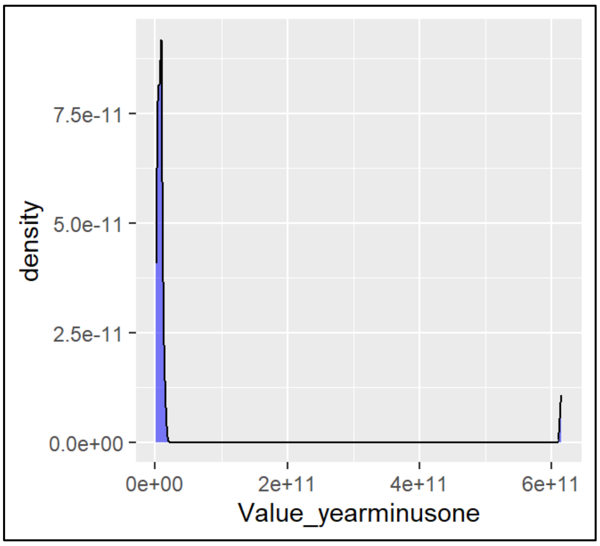


HYPOTHESIS 4

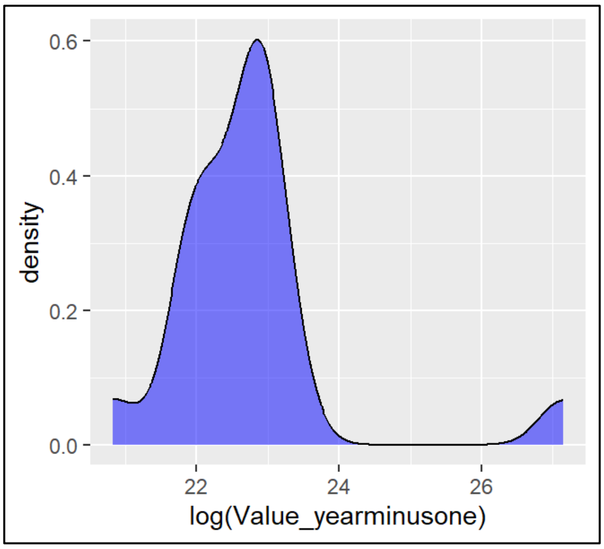
a)

Transport infrastructure investment (t-1)

Before transformation

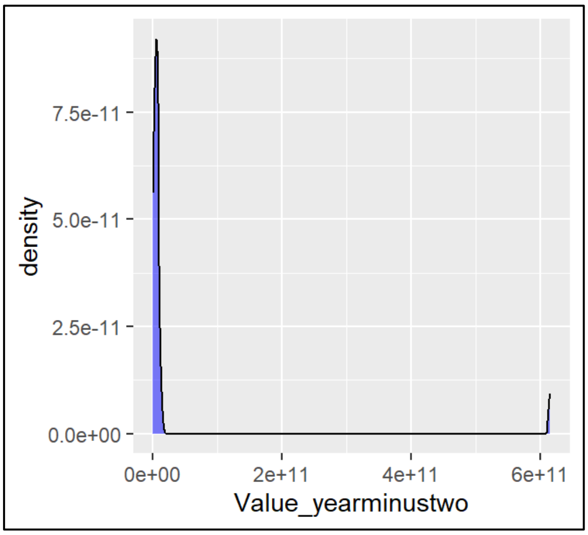


After transformation

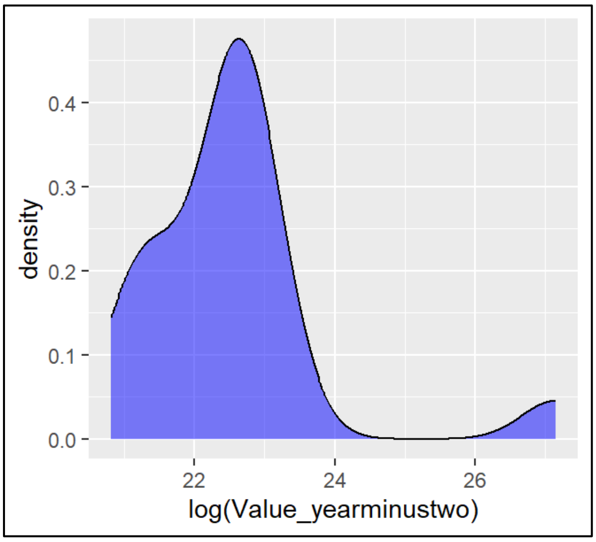


Transport infrastructure investment (t-2)

Before transformation



After transformation



***

OSF Preregistration DOI: https://doi.org/10.17605/OSF.IO/CJKBZ