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MANAGING FOOD INSECURITY THROUGH KNOWLEDGE-BASED SUPPLY CHAINS: CASE OF THE FOOD INDUSTRY IN ZIMBABWE

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Abstract

This paper discusses the influence and relevance of cutting-edge technologies in the development of a knowledge-based supply chain to enhance food security. The application of technologies is based on the background that food supply chains require real-time monitoring and effective information flow from farm to farm with regards to food availability, preservation of quality, health, safety, and accessibility of food from production to the final user. The study used a quantitative approach and drew a sample of 65 employees and suppliers from three food manufacturing organizations (Probrands, Delta Beverages, and National Foods) that are currently using various cutting-edge technologies in Zimbabwe. Further, 80 downstream consumers were drawn from the commonly known food insecure remote areas in Zimbabwe to provide a fair review of the effectiveness of the current food supply chain system (using modern technology). Results show that a number of technologies can be effectively employed when developing a knowledge-based food supply chain. These include artificial intelligence, big data analytics, the internet of things, machine-learning, robotics, additive manufacturing, or virtual reality, among others. These technologies were found to be effective in resolving supply chain management challenges. As a result of reducing supply chain management challenges, food security was found to be improved and customer satisfaction enhanced. However, in the absence of such technologies, it was found that it is difficult to develop effective and sustainable knowledge-based food supply chains in Zimbabwe. It is recommended that all food producers, intermediaries, suppliers, consumers, and other stakeholders make use of knowledge-based food supply chains that are enhanced by different technologies to ensure food security and customer satisfaction.

Key Words: Knowledge-Based Supply Chain, Food Supply Chain, Cutting-Edge Technologies, Food Safety, Food Quality

1.0 INTRODUCTION AND BACKGROUND

Food is the basic necessity for the current world population, standing at 7.96 billion people (Mohammadi, et al., 2022). Food is the third most important factor for living things to supply energy and growth, sustain life, or promote growth, after air and water

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(Hemathilake, & Gunathilake, 2022). In Zimbabwe, about 27% of rural Zimbabweans are estimated to be food insecure during the January to March 2022 lean season (Manyeruke, Hamauswa & Mhandara, 2013). This translates to 2,942,897 individuals who collectively require 262,856 tons of maize. The food supply chain is so delicate to manage as compared to other commodities' supply chains, as food requires top-notch safety and quality management from the farm to the end user. Failure to meet any of the safety and quality requirements may easily result in food insecurity and solving the challenges within a food supply chain system may take a long time at the expense of prolonged food insecurity and customer dissatisfaction. Sustainable management of knowledge and information about food supply chains therefore becomes crucial to ensure the survival of the world's population. According to Yin et al. (2022) it is difficult to program human minds to remember every piece of information in the supply chain, especially when the information overloads. It is at this stage that the use of technology has to be embraced to improve information and knowledge management with regard to food supply chains. This is where cutting-edge technologies are mostly required, to smoothen the process as well as reduce unnecessary costs associated with loss, shortages, contaminations (Oliveira et al., 2022). In the current study, technologies were applied in line with the four pillars of food security, which are availability, accessibility, stability, and utilisation. The study aimed to reveal the importance and impact of knowledge-based supply chains in reducing food insecurity with a focus on the Zimbabwean economy. Three food organisations currently using a number of cutting-edge technologies in their supply chains have been selected to review the significance of knowledgebase supply chains. Zimbabwe is known to have productive and non-productive regions with regards to food production. Productive areas include Mashonaland and Manicaland, whilst non-productive provinces are Matebeleland, Masvingo, parts of Manicaland and also parts of the Midlands. Disparities in food production abilities have caused food insecurity issues amongst non-producing areas (Manyeruke, Hamauswa & Mhandara, 2013). Supply chain management has been playing a very crucial role in enhancing the availability of food to non-producing areas. However, without any technology utilised, there have been perennial challenges of demand and supply mismatch, resulting in unsolved food availability within non-producing areas (Ameen, Hosany & Tarhini, 2021). Moreover, supply chain process risks, transport and logistics inefficiencies, food traceability challenges, and warehouse and storage challenges remain the gaps which food organisations have not been able to solve. The current research paper reviews food organisations that have adopted modern technologies for an average of two years to see if there is any improvement enhanced by the adoption these cutting-edge technologies. The paper will be outlined into 10 sections, which are introduction, conceptual framework, literature review, methodology, results, discussion, conclusion, statement of declarations, author contributions and references.

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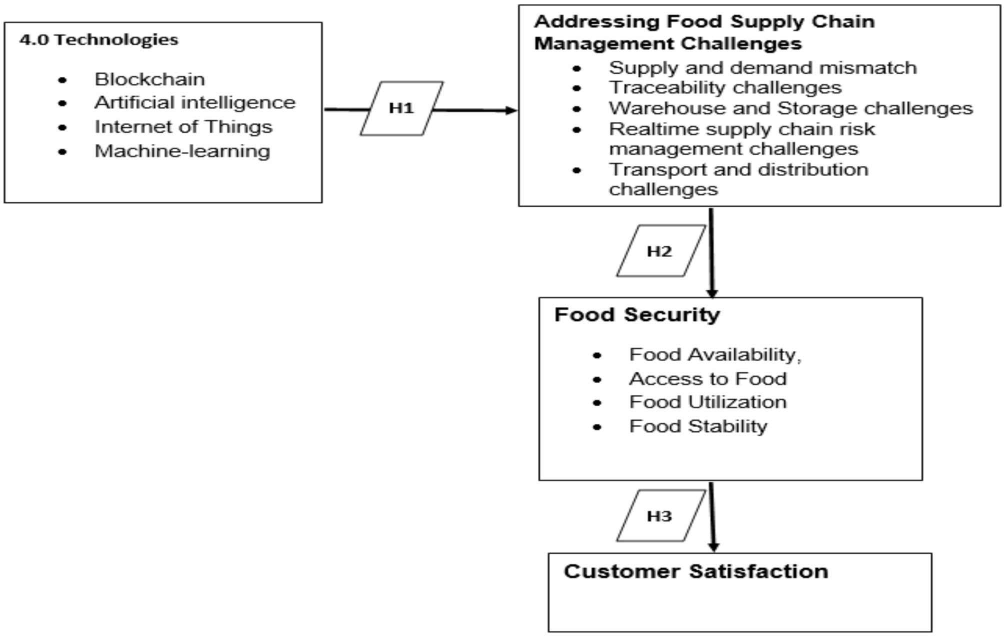
2.0 CONCEPTUAL FRAMEWORK

Figure 1: Conceptual Framework



Source: Own

H1: Implementation of 4.0 technologies has a positive and significant influence on resolving food supply chain management challenges.

H2: Resolving food SCM challenges has a positive and significant influence on improving food security.

H3: Improving food security has a positive and significant influence on customer satisfaction.

3.0 LITERATURE REVIEW

3.1 Knowledge-Based Supply Chain

The term "knowledge-based supply chain" was derived from the term "knowledge-based economy," which describes an advanced economy with a greater reliance on knowledge, information, and high skill levels, as well as an increasing need for business and government sectors to have ready access to all of these. Knowledge based supply chains are those that make extensive use of cutting-edge technology and heavily depend on data knowledge, information, and people skills as the cornerstone for inventive operations, and as such, are crucial to the knowledge economy's overall strategy (Yin et al, 2022).

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A number of cutting-edge technologies such as real-time supply chain visibility, warehouse robots, autonomous deliveries, big data analytics, the internet of things, machine learning, robotics, additive manufacturing, and virtual reality are some of the terms used to describe artificial and augmented intelligence. These and other emerging technologies have been employed in different industries and improved organisational performance and customer satisfaction (Olan et al., 2022). Similarly, in food supply chain management, the same technologies have been found to be helpful in achieving both food security and sustainability (Dora et al., 2021). A supply chain system has to satisfy a number of conditions for any community or nation to achieve food security. Traditional supply chain systems lack the visibility, transparency, and ease of monitoring that technology-aided supply chains do (Humayun, 2021). A selected number of 4.0 technologies are discussed below.

Artificial Intelligence

In recent years, artificial intelligence (AI) has gradually established itself in the logistics industry. AI technologies are now being employed in supply chain management for route planning and scheduling, demand planning, and smart transportation. The application of cutting-edge technologies will have a significant impact because it will be useful in sustainable solutions and will encourage the usage of robotics, last-mile delivery, and automated picking devices. Experts predict that augmented intelligence will be used more to supplement AI in food supply chain. When paired with AI insights, augmented intelligence will provide greater value to businesses by allowing logistics personnel to complete jobs faster while minimising errors such as contamination and perishability (Monteiro, & Barata, 2021).

Supply Chain Visibility in Real Time

Supply Chain Visibility has evolved into an essential tool for any logistics company. SCV improves real-time visibility to meet consumer expectations for real-time monitoring of their orders. Start-ups offering supply chain visibility technology enable businesses to react using real-time information on the weather, roads, and traffic patterns to respond swiftly and correctly to dynamic circumstances (Yadav, Luthra, & Garg, 2021). Discussions regarding supply chain visibility are incomplete without mentioning Internet of Things (IoT) sensor technologies, which are critical tools in tracking shipments (Monteiro, & Barata, 2021).

Advanced Analytics and Data Standards

The logistics business has typically used a fragmented environment to store and process information. As a result, huge inefficiencies have resulted, making it impossible for businesses to digitize their processes. Logistics businesses should expect improved data standardisation in food transportation as a result of the development of mainstream information technology standards (Rejeb, Rejeb, & Zailani,2021). Food supply chain sector will reap enormous gains from digitizing and standardizing data. Furthermore, young startups are collaborating with businesses to digitize their data for forecast

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optimization and advanced analytics, which can aid in demand projections, better supply visibility, assertive linear planning, unforeseen condition detection, preventative upkeep, and last-mile enhancements (Dora et al., 2021).

Robotic Warehouses

For years, robots have walked freely about warehouses, and the application of robotic systems in logistics is projected to become increasingly common in the coming years. The testing of robots in warehouses has increased by 18% year on year (Khandan et al., 2022). Warehouse robotics can assist in loading trucks, transferring boxes, and assembling pallets without the necessity of human labour. This improves the efficiency needed when dealing with perishable foods (Piramuthu, 2022).

Driverless Deliveries

Companies are experimenting with driverless deliveries in order to increase efficiency and save on labour costs. Although regulatory difficulties with driverless delivery cars may take some time to resolve, players in the logistics sector may anticipate that more businesses will come through this cutting-edge technology. to improve distribution efficiencies (Sgarbossa et al., 2022).

3.2 Knowledge Based Supply Chains and FSCM Challenges

The most severe and attention-seeking risk appears to be supply-demand mismatch, preceded by operations and transportation risks. 4.0 technologies significantly reduce supply-demand mismatches, process hazards, and supply chain disruptions. This real-time information enables businesses to respond more quickly to supply chain interruptions and minimize risk (Yin et al, 2022). Placing supply chains online can help businesses achieve the next tier of operational performance while also saving money (Yadav et al, 2021). Common challenges that affect food supply chains with a spill over effect on food security are discussed in the next subsections. Supply and Demand Mismatch In some circumstances, sustainable food supply chain (SFSC) stakeholders' inability to manage a mismatch between supply and demand occurs as a result of increased production and distribution, despite rising customer demand for SFSC products. There are several holes in the food supply chain, and uneven supply lead times are another major impediment to balancing supply and demand. Today's supply chain necessitates determining how to handle demand-driven inventory while also keeping expenses under control and simplifying for efficiency. In the midst of an incredible array of problems, the endeavour is daunting (Sutcliffe, Knox, & Hess, 2021). On the inbound side, retailers are more affected by order and specification alterations, whereas shortages are the top concern for producers in terms of inbound supplies. Similarly, shortages and unrealistic order promises are issues that prevent distributors from receiving the resources they require when they require them. Naturally, all of this inward and outward volatility complicates matching supply and demand. The link between predicting and inventory management demonstrates the difficulty of developing a demand-driven position. A demand-driven system improves forecasting accuracy;

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theoretically, in a demand-driven environment, distribution-intensive enterprises would carry less inventory while meeting higher service standards since they would have an accurate view of demand signals (Manikas, 2022). In the wake of all these challenge matching demand and supply remains a thorn-in the flesh. Transport and logistics inefficiencies Inefficiencies in transport come in different dimensions and mostly range from long turnaround times, lack of in-transit refrigeration for food commodities, and lack of visibility in case there are challenges with food transport vehicles. Irregular route planning and unmanaged fuel consumptions are some of the current challenges contributing to increased transport costs (Sutcliffe, Knox, & Hess, 2021). Food Traceability challenges Organisations that still use traditional paper tracking methods and human inspections are frequently blamed for their food supply chain's lack of effective traceability. These are characterised by inaccurate information being shared and eventual delays. Food shelf life, quality, food loss, and food waste are the common supply chain challenges revolving around a lack of proper traceability (Tan et al., 2022). Customer complaints and dissatisfaction Customers are the end users of supply chain outputs and hence need to be treated with a lot of curtesy. Food quality and safety are the major requirements that customers normally demand in a food supply chain. Consumers and customers have their own tests (Trang et al., 2022). Poor storage and food preservation procedures, transit delays, industrial sabotage, and severe weather are some of the most common causes that impair the quality and safety of food and goods (Sindhu & Kumar, 2022). The next subsections discuss how various cutting-edge technologies make the supply chain more efficient and improve both food security and customer satisfaction.

3.3 Knowledge Based SCM And Food Security

Despite ongoing progress in combating hunger, an intolerable number of people go without the food they need to lead healthy and active lives. The most recent projections indicate that there are over 795 million individuals in the world or slightly more than one in every nine, go to bed each night hungry, while an even bigger number live in poverty (defined as earning less than $1.25 per day) (Mudzielwana, Mafongoya & Mudhara, 2022). Improvements in agricultural productivity are required to boost rural average incomes and access to affordable food, but they are insufficient to assure food security. Food security comprise not only of an appropriate supply of food but also availability, access, utilization, and food stability for individuals of all ages, genders, races, religions, and socioeconomic status. Agriculture is directly tied to food security, while food security is dependent upon an efficient supply chain system. Each country's agricultural industry is dependent on accessible natural resources as well as the politics that regulate those resources. Rice, maize, root crops, sorghum, and cassava are staple food crops that provide the majority of the nutritional energy in the human diet (Pandey, 2021).

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3.4 The Importance of 4.0 Technologies for Food Security

Food security is defined as having continuous economic and feasible access to enough food to meet nutritional requirements for a nutritious, healthy, and productive life. When no one in a household is hungry or afraid of going hungry, the household is food secure. Food insecurity frequently has long-term ramifications for the ability of families, communities, and countries to thrive and achieve. Long-term malnutrition stunts growth, impairs cognitive development, and makes people sicker (Fedotova, 2021). Food security is comprised of four pillars: availability, access, usage, and stability. A person must always have access to sufficient food of the appropriate dietary composition (quality). Those who never get enough decent meals are perpetually hungry (Režek et al., 2021).

Food Access and 4.0 Technologies

Food access essentially refers to a neighbourhood and a home having enough food. True food security requires that individuals have access to a sufficient amount and quality of nutritious food. Food access is influenced by a number of geographical, social, and policy factors. Pricing, household proximity to suppliers, and transportation all have an influence on food access (David, 2022). When analysing national food security, it is crucial to consider not only national production but also the nation's access to food on the international market, its currency exchange income, and its citizens' consumption preferences. Food access at home is determined by a family's income, own food supply, as well as its inhabitants' ability to obtain optimal quality and variety of food in the marketplace. However, the study can only be entirely correct at the individual level because we can only assess the impact of sociocultural disparities on people's ability to meet their nutritional needs by determining who consumes what (Latino et al., 2022). Reducing food losses in production, transit, and storage as well as retail and consumer food waste is an important part of food access. Since there are no ready markets for smallholder farmers, they frequently store their grains in substandard facilities (e.g., no protection against moisture, excessive heat, rodents, and pests), resulting in ruined crops (Rezek et al., 2021). Food loss is frequently referred to as a "farm-to-fork" harm issue (Aung & Chang, 2014); it is characterized as any food product, liquid or solid, cooked or uncooked, thrown away or wasted, including food processors. Food loss is a global issue in both developing and developed countries (de Lange & Nahman, 2015). According to the United Nations Food and Agriculture Organization (FAO), around 40% of food produced is lost or wasted throughout the food supply chain (Warker, 2018). In developing countries, this figure is significantly greater. Before reaching the end consumer, food must pass through a large channel of farmers, retailers, distribution companies, transporters, warehousing facilities, processors, and suppliers, and must go through process steps such as production, harvesting, postharvest, processing (warehouses, packaging), shipping, distribution, and sales. There are five types of losses in the food supply chain: agricultural loss, postharvest loss, processing loss, distribution loss, and consumption loss (Kummu et al., 2012). The majority of food loss

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happens throughout the food system, beginning at farms and finishing at households through post-harvest processing (warehouses, packaging), transportation and distribution, availability in supermarkets, and consumer purchase. Food loss is far more widespread in developing nations in the early and intermediate stages of the supply chain, and it is mostly caused by insufficient supply chain and logistics structures and management, low levels of technology use, and capital efficiency in food production systems. The cultivation, storage, and distribution of high-value perishables like vegetables, fruits, dairy products, and meat are restricted by a lack of electricity and economic refrigeration. Additionally, there is a need for reasonably priced refrigerated transportation to deliver produce from the farm to the market while maintaining freshness and negotiating unpaved, difficult terrain (Buluswar et al., 2014; African Cashew Alliance, 2010). As a result, all crops, but especially perishables, are vulnerable to agricultural losses. For preservation, handling, refrigeration, shipping, and processing, a multitude of post-harvest loss devices are helpful. For instance, threshers are anticipated to decrease post-harvest grain loss from 4.87 percent to 0.01 percent, equating to a savings of $12 million in Uganda. The threshers should also increase employment prospects, labour productivity (saving up to 59% of the time spent threshing), and grain quality (Okiror et al., 2021). Utilizing internet of things and blockchain based food tracking system allows the food supply chain to assess the degree of safety of perishable food products by tracking their path from where they are grown, handled, or stored to how they are transported or processed. This results in the creation of an authentic and transparent chain of records for the food ecosystem (Godsiff, 2016). The provenance and artificial intelligence traceability of information in the food sector help to increase the quality and safety of food (Saberi et al., 2019). Additionally, the advancement of technology in the era of 4.0 technology has the potential to reduce wasteful spending and the financial burden associated with outbreaks, cross contamination, and product recalls. Many sectors have considered using cutting-edge technology, such as the Internet of Things (IoT) and blockchain, to improve traceability (Sun et al., 2022). Numerous initiatives in Canada are utilising nanotechnology to enhance agricultural preservation and lower the likelihood of food loss. In order to keep fruit fresh, a nanotechnology-based smart packaging system was created, utilising hexanal-impregnated packaging and coatings generated from banana stems and other agricultural waste (Green et al., 2021). More technologies are being used around the world to provide access to food, such as thermal battery-powered milk chillers, better genetic variants, and technology for drying seeds and grains. Additionally, advances in aeration and preservation technologies, inventive packaging, biowax coating, effective pulse processing technology, and the creation of cool stores are all contributing to increases in food access (Fedotova, 2021). The use of advanced cleaning, grading, and packing techniques, low-cost refrigerated vehicles, low-cost solar dryers, and vacuum or hermetic sealing systems can significantly increase food access in several African nations (Sibanda & Mwamakamba, 2021).

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The Improvement of Food Availability Through Technology

The availability of sufficient quantities of food in acceptable quality, whether it comes from domestic production or imports, including food aid, is referred to as food availability (FAO, 2006). According to Chávez- Dulanto et al., (2021), the presence of food in a community is what is meant by "food availability." This and the efficiency of food production are closely related. When essential resources, like water for irrigation, are scarce or when agricultural land is damaged or degraded, food availability can become a problem (David, 2022). According to Yin et al., (2022), emerging cutting-edge technologies like big data, artificial and augmented intelligence, the internet of things, blockchain, and others have the potential to have a positive impact on all food supply chains and contribute to increasing food availability. Precision farming, gene editing, biological crop protection, and technologies that improve traceability from farm to fork are some examples of specific technologies. These advancements can help to improve resource- and climate-efficient food systems. Less food will be wasted, and supplies will be increasingly dependable as a result of improved communication between food producers, traders, and consumers. One approach to doing this is to trace inventories from the field to the store with radio-frequency identification (RFID) tags (Hemathilake & Gunathilake). Perishable goods can also be preserved in the best possible ways and provide information about each good's origins that can be utilised to prevent the propagation of foodborne diseases. By increasing the effectiveness of the supply chain, RFID technology can assist in increasing food security (Humayun, 2021). Below are discussions on how 4.0 technologies (knowledge-based supply chains) help to improve food availability. Greater Transparency and Accuracy A company's supply chain ecosystem may house thousands of suppliers who work in the food industry. Any gaps in supply chain risk management can result in supply chain disruptions, missed revenues, and excessive costs in such circumstances, making it vital to ensure end-to-end transparency and real-time asset tracking (Astill et al., 2019). By going digital, businesses can track the whole food supply chain in real time, including determining the precise location of commodities (on order, in transit, or in a warehouse). By combining IoT data with notifications from supply chain partners, sophisticated solutions make inventory tracking simple. This boosts lot and batch management, optimizes inventory, minimizes associated expenses, and reduces out-of-stock situations while also improving order accuracy and projected time of arrival (Stranieri et al., 2021). The unevenness of information can be eased by information technology, particularly the embracing of social media by farmers in different parts of the world. Farmers are able to get information about markets easily so that they can supply where there are requirements. Digital technologies can assist farmers in making more accurate judgments about resource management by providing, processing, and analyzing a growing amount of data more quickly. They may also reduce scale economies in agriculture, enhancing the competitiveness of small-scale producers. Inequalities in access to information, expertise, technologies, and markets can be reduced with the

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use of digital technologies, which can also help farmers make more accurate resource management decisions (Shamika et al., 2020). Use of Irrigation technologies to increase food production In the quest to ensure and raise crop output, the availability of water is a crucial component. Due to physical water scarcity and economic water scarcity as a result of underinvestment in water infrastructure or human capacity issues to meet water demand, many farmers lack access to water for agriculture, leading to unavailability of food. In this regard, low-cost and cheap drills, pumps powered by renewable energy sources, and technology for desalination and increased water efficiency may be able to address these issues and production, resulting in improved food availability (UNCTAD, 2017). Salts and minerals that make water unfit for human consumption or crop irrigation can be removed by water desalination technology like off-grid solar-powered electrodialysis reversal (EDR) devices. Groundwater may become more accessible as a source of irrigation with the use of lightweight drills for shallow groundwater and technology to identify groundwater. Solar-powered irrigation pumps may make irrigation more widely available. Affordable rainwater storage systems are another viable irrigation technique, and greenhouses can help farmers extend their producing season throughout the year by reducing the impact of erratic rainfall on water availability (Shamika, Bob, Ulrich, Bernadette, Adrian, & Lin, 2020). In fragile natural ecosystems, the Groasis Waterbox technology can increase water efficiency to meet rising agricultural output demand. The Groasis Waterbox is an integrated planting technique that encircles plant bases, collecting dew and rainwater beneath the plant to create a water column, and distributing that water over extended periods of time to prevent evaporation (Al-Anzi, 2022). Improved Plant Varieties and Higher Crop Yields Through Crossbreeding The fortification of nutrients, drought tolerance, diseases, herbicides, or pests, and increased yields can all be achieved by genetic modification of plant species. Crossbreeding techniques have been used in earlier agricultural forms of genetic manipulation (Shamika, Bob, Ulrich, Bernadette, Adrian, & Lin, 2020). Such a technology is nevertheless helpful, especially for farmers across a variety of geographies, despite the fact that plant modifications are restricted to the greatest features available within the same family of crops (Buluswar et al., 2014). The Pan-Africa Bean Research Alliance has improved household food security and nutrition in Ethiopia for an estimated 3.98 million people by promoting the wide adoption of excellent protein maize (QPM) varieties among maize growers and consumers (Kondwakwenda, et al., 2022). Managing the Soil to Increase Agricultural Production Afforestation of crops and the eradication of pests and illnesses are now more prominently featured in technical advancements and breakthroughs and less on environmentally sound soil management techniques. On the other hand, healthy soils with fewer pests and illnesses support the growth of healthy plants (Shamika, Bob, Ulrich, Bernadette, Adrian, & Lin, 2020). Artificial fertilizers have been used to increase agricultural yields for a long time, but they need a lot of capital and rely heavily on natural gas, particularly in the case of nitrogen. New technologies that make organic fertilizers (composting, manure, or dung) more feasible and effective could eventually replace synthetic fertilizers (Al-Anzi, 2022).

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Food Utilisation and 4.0 Technologies

According to food utilisation, not all food is equally valuable or sufficient. It is essential that the food being obtained is of a high caliber in order to be food secure (Konur et al., 2021). Food must be nourishing and healthy enough to give people the energy they require for their everyday tasks. Additionally, it is essential that people have the skills and knowledge needed to effectively "utilise" the food that is accessible to them. This entails having the tools necessary to appropriately choose, prepare, and preserve readily available and easily accessible foods. Utilising 4.0 technology in food preparation and packaging can extend food's shelf life and increase food safety (Stranieri et al., 2021). In the food industry, using machines also guarantees affordability and high quality. Utilising technologically advanced machinery lowers the cost of maintaining food freshness and boosts output (Kondwakwenda, et al., 2022). Utilising food effectively converts the food a household has access to into nutritional adequacy for its members. Analysis of distribution in terms of need relates to one element of use (David, 2022). Although there are nutritional criteria for the actual dietary requirements of men, women, boys, and girls of all ages and life phases (including pregnant women), these "needs" are frequently socially manufactured based on culture. For instance, research from South Asia reveals that women typically eat later than men in the same family and are less likely to eat desired meals like meat and fish. Poor food utilisation, or an individual's diet lacking the ideal ratio of macro- (calories) and micronutrients, frequently causes hidden hunger (vitamins and minerals). People may appear to be well-fed and consume enough calories, but they may be lacking in important micronutrients like vitamin A, iron, and iodine (Pandey, 2021). Systems of effective food control are necessary to safeguard consumer health and safety. They are also essential for giving nations the ability to guarantee the safety and quality of the foods they export to other countries and to make sure that imported foods meet local standards. Food security is the idea that everyone, especially most disadvantaged, has unhindered access to a sufficient supply of nutritious, culturally acceptable food that will completely support their physical, mental, and spiritual well-being (Sindhu & Kumar, 2022). Food quality and food safety can be used interchangeably, but food safety alludes to any risks to human health, chronic or acute, that may result from the use of food (Wu & Hsiao, 2021). All additional characteristics that affect a product's value to the end user are considered to be part of food quality. This contrast between safety and quality has significant effects on how policies are created and determines the type and focus of the food control system that is best suited to achieve predetermined goals for the safety of the nation and its people (Pandey, 2021). Since the advent of preventative strategies like Hazard Analysis and Critical Control Points (HACCP) in 1960, there has been a greater emphasis on managing the risk factors associated with food safety Gehring & Kirkpatrick, 2020). It is a methodical approach to food safety that focuses on physical, chemical, and biological risks as a means of mitigation rather than on the inspection of the final product. The food industry uses HACCP to recognize possible food safety hazards so that important steps can be taken to lessen or minimize the likelihood of the hazards materialising (David, 2022).

Food stability and 4.0 Technologies

Access, availability, and consumption of food should be somewhat steady throughout time in order to be considered to have good food stability. Any dangers to this stability should be reduced to a minimum. Natural catastrophes, climate change, conflict, and economic issues, including sharp price swings, pose threats to the stability of the food supply (Konur et al., 2022). When a community, family, or individual has constant access to food and is not at risk of losing that access due to cyclical occurrences like the dry season, the situation is said to be in food stability. When someone is malnourished due to a lack of necessary nutrients, their food intake is unstable (Astill et al., 2019). Precision farming, insurance, and farmer decision assistance are just a few of the agricultural applications that can benefit from big data and the Internet of Things. Depending on the vegetation index it creates using satellite imagery, it gives information about crop health to farmers and businesses, ultimately helping producers make decisions about what to do and what not to do to ensure crop health. To preserve food stability, it is also possible to employ the cloud-based global agricultural monitoring system, which makes use of indicators from remote sensing and climatology on various scales. First, indices for rainfall, temperature, photosynthetically active radiation, and potential biomass are used to analyse the trends of crop environmental conditions worldwide. Together, they describe the crop status, agricultural intensity, and stress, which is the perfect way to assess the stability of the food supply. Additionally, several nations are utilizing hyperspectral imaging, which is cantered on drones and satellites (Green et al., 2021). Al-Anzi (2022) went on to discuss how early warning systems and precision agriculture can help with issues related to food stability.

3.5 Customer Satisfaction

Consumers are showing an unprecedented level of interest in how food is produced, processed, and sold, and they are urging their governments to take on more responsibility for ensuring the safety of food and protecting consumers. This job entails formulating plans to improve food control systems in order to safeguard the public's health, stop fraud and deception, avoid food adulteration, and ease trade. They will give authorities the ability to select the choices that, in terms of legislation, infrastructure, and enforcement methods, are best for their food control systems. It is important for food supply chain stakeholders to understand customers' perceived quality. Additionally, the combination of food quality and price needs to be observed as it is one of the factors contributing to customer satisfaction. Hamali, Prihandoko, Kurniawa and Ramdhani (2020) explained that the use of 4.0 technologies such as block chain and artificial intelligence helps to improve food production, food quality, safety, and overall food costs. Customers are more satisfied when they can achieve a combination of high quality and low prices, and this can easily be obtained by the use of modern technologies (Tayal et al., 2021).

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4.0 METHODOLOGY

The study employed a quantitative approach and a total of 145 respondents; 65 drawn from three food manufacturing organisations (Probrands, National Food Limited and Delta Beverage) that are currently using various cutting-edge technologies in Zimbabwe and 80 being downstream consumers drawn from the commonly food-insecure remote areas in Zimbabwe to provide a fair review of the effectiveness of the current knowledge based food supply chain system.

5.0 RESULTS

Measurement and structural equation modelling were used to analyse the study data. The measurement model examines the relationship between the latent variables and their measures. As a result, during the examination of the measurement model, indicators with relatively low loadings of less than 0.60 are disregarded (Gefen & Straub, 2005). No factor was excluded from the current investigation as an outcome of low loading. Construct reliability was assessed using Cronbach's Alpha, rho A, and Composite Reliability (CR) coefficients, all of which above the internal consistency cut-off of 7.00. Convergent validity was seen to be good when the average extracted variance (AVE) was more than 0.50. (Dijkstra & Henseler, 2015). Every latent variable had AVE values greater than 0.50. Table 1 summarizes the instrument's validity and reliability as well as the factor loadings. According to Table 2, which shows the square roots of the AVE for constructs with a higher correlation than the inter-construct correlation, discriminant validity was proven using the Fornel-Larcker criterion. Additionally, heterotrait-monotrait ratio coefficients (HTMT) with values below the 0.90 cut-off were used to evaluate discriminant validity (Hensler et al., 2015). As a result, it was determined that all research constructs had sufficient discriminant validity.

Table 1: Reliability and validity

Latent & Observed Variables	Factor Loadings	Cronbach's Alpha	Rho_A	Composite Reliability	AVE
4.0 Technologies		0.968	0.972	0.973	0.816
IT1 <- Implementation of IoT Technology	0.891				
IT2 <- Implementation of AI Technology	0.914				
IT3 <- Implementation of Aug I Technology	0.884				
IT4 <- Implementation of Robotic Technology	0.905				
IT5 <- Implementation of other Technologies	0.897				
IT6 <- Machine Learning Technology	0.910				
IT7 <- SC Reality Technology	0.906				
IT8 <- Blockchain Technology	0.919				
Resolving SCM Challenges		0.953	0.959	0.963	0.813
SCMC1 <- Demand and Supply Mismatch	0.949				
SCMC2 <- Traceability challenges	0.903				
SCMC3 <- Transport and distribution	0.895				
SCMC4 <- Information asymmetry	0.794				

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SCMC5 <- Exorbitant SC costs	0.943				
SCMC6 <- Customer complaints	0.917				
Customer Satisfaction		0.985	0.986	0.987	0.916
CS1 <- Food is readily available	0.954				
CS2 <- We can access food anytime	0.956				
CS3 <- We have no fear of hunger	0.959				
CS4 <- We are able to afford food	0.971				
CS5 <- We are aware of food nutrition	0.971				
CS6 <- Family members all get nutritious food	0.944				
CS7 <- We receive constant supply of food	0.943				
Food Security		0.967	0.968	0.976	0.911
FS1 <- Food Availability	0.955				
FS2 <- Food Access	0.958				
FS3 <- Food Utilisation	0.950				
FS4 <- Food Stability	0.954				

Table 2: Fornell-Larker Criterion

	Customer Satisfaction	Food Security	Implementation of 4.0 Technologies	Resolving SCM Challenges
Customer Satisfaction	**0.957**			
Food Security	0.667	**0.954**		
Implementation of 4.0 Technologies	0.728	0.656	**0.903**	
Resolving SCM Challenges	0.708	0.749	0.781	**0.901**

Table 3: Heterotrait-Monotrait ratio (HTMT)

Latent Variables	Customer Satisfaction	Food Security	Implementation of 4.0 Technologies	Resolving SCM Challenges
Customer Satisfaction	0.000	0.000	0.000	0.000
Food Security	**0.681**	0.000	0.000	0.000
Implementation of 4.0 Technologies	**0.749**	**0.682**	0.000	0.000
Resolving SCM Challenges	**0.722**	**0.765**	**0.793**	0.000

Structural Model

Path Analysis and Hypotheses Assessment

The R^2 and Q^2 scores as well as pathways significance have been utilized to analyze a structural model. The robustness of each structural path, as gauged by the R^2 for the predicted variables, determines the model's goodness of fit (Hu & Bentler, 1999). R^2 should be higher than or on par with 0.1. (1992; Falk & Miller). Table 4's findings show that all R2 ratings are more than 0.1, establishing a predictive potential. The predictive value of endogenous elements is further demonstrated by Q^2. When the Q^2 score is higher than 0, the model is considered to be predictively significant. The findings show that the constructions' significant predictability (see table 4). Additionally, to evaluate

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model fit, the standardized root mean square residual (SRMR) and the Normed Fit Index have been used (NFI). The SRMR was 0.090, below the 0.10 cutoff, indicating a satisfactory level of model fit (Hair et al., 2018). The NFI was 0.963, indicating a good and adequate model fit in the permissible range of 0.9 to 1 (Moss, 2021). Hypotheses were assessed to establish the importance of the relationships evaluated. H1 Assessed the influence of implementing 4.0 technologies on resolving food supply chain management challenges. The results indicate that implementing 4.0 technologies have a positive and significant influence on resolving food supply chain management challenges ($\beta=0.781$, $t=20.352$, $p=0.000$), with a t-value greater than 1.96 and a p-value less than 0.050. As a result, H1 is supported and confirmed. Kayikci et al, (2022) reaffirmed that the manifestation of 4.0 technologies helped a long was in easing up to 75% of food supply chain challenges. From information management, management of the flow of food and payments were all made simpler and more efficient. Piyathanavong et al, (2022) reiterated that reliable and robust tools are available in the Industry 4.0 technologies to assist trace the food throughout the supply chain from the farm through processing until it reaches the end-users and, thus, ensure transparency. H2 Assessed the influence of resolving food SCM challenges on improving food security. The data revealed that resolving food SCM challenges has a positive and significant influence on improving food security ($\beta=0.749$, $t=11.404$, $p=0.000$), as a result, H2 was confirmed and supported. Food security depends on movement of food products from productive to non-productive regions through efficient and effective supply chain process. As organisations successfully work through a number of food supply chain challenges such as food loss, food waste and distribution inefficiencies, the positive result is managed food security (Nekmahmud, 2022). H3 evaluated the influence of improving food security on customer satisfaction. Review of the results ($\beta=0.667$, $t=16.369$, $p=0.000$) indicated that improving food security has positive and significant influence on customer satisfaction and hence H3 was supported. According to Latino et al., (2022), nutritious and adequate food supply is vital to human survival and satisfaction. Once a focus is made to improve all the four pillars of food security (food availability, access, utilisation, and stability) then there is guaranteed satisfaction on the customers and end-users.

Table 4: Hypothesis Assessment and Model fit

	Original sample (O)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	2.5%	97.5%
Implementation of 4.0 Technologies -> Resolving SCM Challenges	0.781	0.038	20.352	0.000	0.703	0.850
Resolving SCM Challenges -> Food Security	0.749	0.066	11.404	0.000	0.618	0.876
Food Security -> Customer Satisfaction	0.667	0.041	16.369	0.000	0.577	0.738
		R-square	**Q-Square**			
Customer Satisfaction		0.445	0.452			
Food Security		0.561	0.487			
Resolving SCM Challenges		0.610	0.377			
		SRMR	**NFI Index**			
		0.090	0.963			

Source: Data Analysis

6.1 DISCUSSION

The study results indicated that implementation of 4.0 technologies significantly helps to reduce and resolve food supply chain management challenges. More-so the results show that resolving supply chain management challenges positively contributes to improved food security. Further the results depict that improved food security increases customer satisfaction. The study results are in sync with previous studies done by (Klerkx and Rose (2020) which indicated that customer satisfaction in the food industry is a function of efficient supply chain management backed by cutting edge technologies such as blockchain, artificial and augmented intelligence, internet of things and robotics. Results of the study were merely based on food producing companies in Zimbabwe and downstream customers that are supplied by the same food producing companies and results are a reflection of those variables. Results from the three hypotheses assessed are all in agreement with existing literature as indicated in the literature review section of the study.

7.1 CONCLUSION

The purpose of this research was to reveal the importance and impact of knowledge-based supply chains (supply chains with cutting edge technologies) on reducing food insecurity with a focus on the Zimbabwean economy. Based on the analysis performed, it can be concluded that knowledge-based supply chains help to reduce food supply chain challenges and also contribute significantly to food security and end user or customer satisfaction. Future exploration into the impact of knowledge-based supply chain management could be useful in other industries other than food sector.

8.1 STATEMENTS AND DECLARATIONS

All the authors have no conflicting interests that are significant to the content of this paper to declare.

9.1 AUTHOR CONTRIBUTIONS

The study's conception and design were contributed to by all authors. Shakerod Munuhwa was in charge of material preparation, data collection, and analysis. Shakerod Munuhwa wrote the first draft of the manuscript, and all authors provided feedback on previous drafts. The final manuscript was read and approved by all authors. No funding was received to assist with the preparation of this manuscript.

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