

Are Smart Refrigerators the Way of the Future for Storing Food?

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Abstract

Smart refrigerators are changing the way people store food by using new technologies, including Wi-Fi, artificial intelligence (AI), internal cameras, voice control, and inventory management systems. This article looks at how smart refrigerators are changing in homes and businesses, and how they could make things easier, cut down on food waste, and save energy. New technologies, including Wi-Fi, internal cameras, voice control, artificial intelligence (AI), and inventory management systems, are transforming how consumers keep food in smart refrigerators. In order to reduce food waste, save energy, and make life easier, this article examines how smart refrigerators are evolving in households and workplaces. The study examines the current market, user benefits, and technology issues to determine whether smart refrigerators are a practical innovation or only a fad. Concerns like cost, long-term reliability, and data privacy are also covered. The essay looks at the existing market, the benefits to users, and the technological problems to see if smart refrigerators are a useful new idea or just a luxury trend. It also talks about worries about data privacy, cost, and long-term dependability. Ultimately, the article wants to find out if smart refrigeration is a big change in how food is stored or just a small change in how appliances are made.

Keywords: Smart appliances, refrigeration technology, internet of things (IoT), food storage, energy efficiency, AI (artificial intelligence), and home automation

INTRODUCTION AND BACKGROUND

As the world's population continues to grow and food waste becomes increasingly unavoidable, there is a growing interest in home food preservation methods. Over the 175 years since the refrigerator was invented, there have been subtle but constant changes in how it looks and how it is used, mostly with the kitchen's biggest and most energy-hungry appliances [1, 2].

Temperature is the first, most important, and frequently the only factor that home refrigeration systems use to keep food fresh. The supply side view is given more weight by certain indicators, such as cooling capacity and duration, and certified research-grade monitoring. Most of this content is about surface parameters (conditions that are expected to be in the store) and food categories that are thought to be able to "sit on the shelf." In addition, decisions regarding storage and ordering have not changed much since the early 1970s, even though catalogue and shop formats and product forms have changed significantly [3, 4].

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The History of Refrigeration

Over the years, several important changes have been made to refrigeration systems. People in China initially used ice to keep food fresh circa 3000 B.C. The first man-made method to keep things cold was invented by the end of the 1700s.

American inventor Oliver Evans developed the first vapor-compression refrigeration device in 1805. General Electric manufactured the first refrigerator for home use in 1911. The first refrigerator with a separate freezer compartment was developed in the 1930s [5–7].

Smart home devices, including smart lighting, smart meters, voice assistants, and smart refrigerators, are new technologies that have emerged in the last few years. Different types of applications can be used to monitor, control, or automate these devices from a distance. They are linked to communication networks. Smart home devices and technology platforms work together to make the concept of linked living possible [8–10].

The Rise of Smart Home Devices

Rising urbanization makes a big difference in how people live, having a significant impact on both their dwellings and their daily lives. The continued development of other smart home devices (OSHDs) and their increasing interconnection also contribute to substantially improving people's quality of life. In the early 1990s, OSHDs made Home Energy Management Services (HEMS) possible. This led to the idea of the Energy Internet, which would allow existing home energy management devices (HEMDs) to work together and connect to each other. Smart management systems for time and travel, such as the smart water management system (SWMS), were also suggested in the early 2000s. Studies focusing on time and engagement have led to the development of Home Automation Systems (HAS), which allow consumers to fully connect and operate their home appliances.

A large part of the world's CO₂ emissions comes from homes, and studies reveal that reducing emissions relies heavily on secondary energy, which is strongly tied to changes or suggestions made to end-user devices. Simultaneously, the new real estate housing policy for state-owned homes is making more people move into shared economic homes, such as more congested local subdivision houses. Digital smart devices assist in collecting interactive data in HEMDs and are becoming an important part of making short-term rental housing more convenient for residents. These types of housing include rooms and apartments. To ensure that the Home Digital System (HDS) continues to follow user trends, the design of Security and Intelligence throughout the installation and operation phases of OSHDs needs to be improved.

KEY TECHNOLOGIES IN SMART REFRIGERATORS

Food storage technologies have long been secret partners in the growth of society. The transition from earth pits or caves to evaporative coolers, and subsequently to icehouses and electric refrigeration during the Second Industrial Revolution, established the cornerstone of human civilization and altered the trajectory of history. People naturally expect things to change 170 years after the modern refrigerator was invented. People think that the emergence of Smart Home Devices, which are an extension of Smart Cities, is considered a major turning point in the history of human society. Over the last ten years, the focus has slowly shifted from monitoring and managing entire cities to monitoring and controlling gadgets in homes and offices. The Smart Home Device Ecosystem includes an air cleaner, dehumidifier, humidifier, bathtub, air conditioner, washing machine, microwave oven, dishwasher, toilet brush, and refrigerator. Three main factors shape this trend: sustainability, health, and convenience. To find the right product for the limited convenience goal, people need to know the different basic protocols used in the air treatment, water treatment, and food processing industries. Therefore, more research is needed to determine whether Smart Refrigerators can add any new value.

Although there is limited academic research on Smart Refrigerators, the duty cycle shows that possible features are starting to appear. A lot of time spent in a home, up to 14 h with no door opening for half a day, is a great opportunity to quickly and effectively gather and analyze data. Sensors that are connected and A.I. The three main features of Smart Refrigerators are Edge, Energy-Efficient Thermal Management, and a long duty cycle. These features work together to enhance functions and personalize experiences.

Sensors, Connectivity, and Integration with the Internet of Things

Smart refrigerators have many sensors that help keep track of and manage food. Sensors for temperature, humidity, light, vibration, and door position provide real-time information on how the system works. Cameras and capacitive sensors track inventory and access. A microcontroller processes the data from the sensors and sends it wirelessly using the latest connectivity options. Wi-Fi is still the main way to communicate, and it allows you to check the status and operate things from outside the building using mobile applications. Bluetooth, Zigbee, and near-field communication (NFC) are other popular technologies that are mostly utilized for short-range interactions with other devices, such as smartphones or tablets. The Global System for Mobile Communication (GSM) allows communication to continue even when the local network goes down. However, GSM alone supports only a few basic functions. Smart refrigerators are becoming increasingly compatible with smart home systems, such as Apple HomeKit, Amazon Alexa, and Samsung SmartThings, as houses become more linked. This kind of interoperability makes it easier for more people to access the refrigerator by allowing more than one device to obtain products from it and provide further information.

AI at the Edge: Automation and Features that Predict

Fridges have many built-in sensors that help them determine what they need to do and carry out automatic tasks. They can make smart decisions by combining a wide range of learning-based insights with contextual knowledge [1, 3], such as what users do, how the system is performing, social feeds, and other sources. Instead of depending on a set of rules, such as those based on time or temperature. For example, refrigerators with environmental sensors can use occupancy data and events such as door openings to decide whether to turn on energy-saving settings. They can learn to connect certain dishes with certain smells, colors, and ways of chilling, and they can suggest changes to how you cook. Based on information about the ingredients, how long they have been sitting, and what else is going on at the same time, they can guess how long it will take for anything to go bad. They can monitor changing preferences and change the defaults as needed.

These features affect how users interact with the gadget. For example, tracking your eating patterns and cooling settings can help you receive proactive temperature notifications. It is possible to identify problems ahead of time and suggest ways to fix them. Algorithms can also encourage better stocking by creating meal plans, combining things that go well together, and mimicking gateways that move life cycles forward while letting you know when the best replacements are available. These features not only make everyday life easier but also help reduce waste by preventing spoilage through good maintenance and planning.

Managing Heat and Energy Use

To maintain the appropriate temperature inside the cavity and use as little energy as possible to keep people comfortable, refrigerators mostly use vapor-compression cycles. The thermostat senses the temperature inside the fridge and turns it on and off as required. This is why the refrigerator runs in cycles. To control this constant cycling motion, many thermal elements are used, such as thermal mass and thermal insulation. Thermal insulation prevents heat from entering and exiting the refrigerator cabinet. The thickness of the thermal insulation depends on the type of insulation material and how well it meets the specified maximum heat loss requirement. One of the most important factors in ensuring the safety and shelf life of food products is to keep them at the right temperature. Most studies and food safety rules focus on maintaining food at the right temperature when it is being shipped and delivered to the end user. After that, it is up to the end-user systems at the retail and household levels.

HOW THE APP WORKS AND HOW EASY IT IS TO USE

Refrigerators are an important part of the human diet because they are the main storage place for food. Refrigerators slow down the process of deterioration, keep food fresh for longer, and ensure that food is stored at the right temperature to maintain its quality. Smart refrigerators take regular cooling units to the next level by adding Smart Home Device ecosystems. Smart home devices can connect to

the Internet and share information with each other. Smart appliances, computers, and smartphones allow users to connect and control items from a distance, making it easier to monitor things, make changes, and receive notifications in real time. Smart refrigerators help keep food fresh, control the conditions under which it is stored, prevent rotting, and send reminders when food is about to spoil. These features affect how people dispose of food and the amount of food they waste. These factors help make food safer and reduce waste, which is beneficial for people, the environment, and the end of life.

People buy smart refrigerators that help them reduce trash and other sustainable technologies, such as electric cars and bulbs that save energy, because of social and environmental issues. These gadgets improve food safety and knowledge of how long food lasts, which is lost along the way from manufacturing to consumption. Knowledge retention encourages people to discard fruits and vegetables that are about to go bad before they can eat them. In addition, the way things are done in the home affects how to handle shelf-life parameters that are not normal, such as those that suppliers provide when they talk about changing supplier-available information, seasonal supply, or other factors. These situations necessitate the formulation of targeted solutions, including the integration of refrigerator-smart-hub appliance connectivity in kitchens. Food waste is a major problem that happens before cooking and leads to the wrong way of getting rid of it.

Keeping Track of Inventory and Expiration Dates

It is now easier to automatically track stored items in refrigeration systems. Smart refrigerators can find food and provide information about how it was used and eaten. The input that these refrigerators provide helps consumers change how they utilize and eat food. Many pieces of information can be used to keep track of things, such as expiration dates, weight, freshness, and the amount of food remaining. Therefore, consumers receive reminders and notifications about this information.

Many forms of storage can be used to keep track of food stored in a refrigerator. Intelligent shelves and automatic weight detection are examples of complex systems that require changes in the construction of refrigerators or chillers. These changes make it difficult for ordinary people to move and use these systems on a larger scale. The ideal way to store food in the refrigerator is to use barcodes (QR codes or stickers) and pictures of the food. This is because they are easy to use, widely available, and can be easily moved between systems. Therefore, this method is a step closer to reducing the carbon footprint.

Remote Monitoring and Mobile App Interfaces

Remote monitoring and mobile app interfaces that work with touch screens, tablets, and smartphones make it easier to control and maintain these smart refrigerators. The Samsung Family Hub™ and LG Smart ThinQ™ are two commercial models that have large screens, allow online purchasing, allow video streaming, keep track of how fresh your food is, and sound alerts for power outages or food expiration. Most of the time, these systems require people to enter food information manually, such as putting labels on food and writing down when it will go bad. Wi-Fi and GSM wireless connectivity connects IoT devices, sending alarms and food information directly to consumers. Ongoing advances are aimed at recognizing food, organizing databases, and keeping track of goods that are about to go bad. Smart chest freezers are still uncommon in the IoT ecosystem.

Smart Cooling Modes and Access Control

Smart refrigerators provide new ways to chill and manage food to keep it fresh for longer. Smart cooling modes choose the temperature based on the type of food, packaging, and container. Access control, on the other hand, controls who can use the system based on their permission level. The modes are automatically turned on based on the sensor input or scanning. This affects power, settings, and reliability.

Food preservation, packing type, when to eat, freshness estimation, container visibility, exposure sensitivity, and event perception all affect the cooling mode. Different methods of preserving food, such as rapid freezing for semi-solid foods and soft freezing for candy, can help it last longer. You may need

to change the settings for open or closed containers, clear or opaque bags, or shelves inside or outside. Family consumption behavior shows that people buy and keep an eye on particular foods for a longer period. The choice of quick chilling, soft freezing, or no cooling is affected by the temperature sensitivity, the amount of available information, and the timing of the action. Power-off, holiday, and travel modes are used when the unit is not being used, when it is on a long break, or when it must maintain its temperature at a certain level. Even when the user is not present, they should still receive information about the food's contents and state. 1 and 2: Automation and authorization systems make it easier for people to control their meals without putting too much pressure on them.

EFFECT ON FOOD SAFETY AND WASTE

Poor storage conditions for chilled food can lead to safety problems and excessive waste. Smart refrigerators let you keep an eye on and control the conditions in which food is stored, which can help with these problems. They make it easier to keep track of inventory and expiration dates, which makes people more aware of what food they have and helps them make better choices about what to eat. Data logs and analysis help identify problems, make it easier to follow food safety rules, and make it easier to follow government rules.

Insights based on data affect consumer behavior and store operations. You can obtain useful metrics such as temperature profiles, duration of cooling cycles, and shelf-life estimates. More openness helps people make better decisions both before and after purchase, and it also draws attention to goods that are at risk of being purchased. Technology works well in business settings and makes it easier to trace food from the farm to the fork, making monitoring and compliance more comprehensive.

Using Data-Driven Insights to Cut Down on Spoilage

Smart home devices are the next big thing in food storage after refrigerators, home electric supply, and timers. Early freezers were able to restock ice blocks for static storage, but automated procedures have improved over the years. Smart home devices make it easier to connect to the Internet, over 100 years after the first home supply of kV. According to Juniper Research, there will be 487 million Smart Home Devices in use worldwide in 2023, with the majority in Western markets. Connected Living reaches both the Water and Energy objectives in the Smart Home range.

Two-thirds of Smart Home Devices come with sensors, Wi-Fi, and low-power protocols. These are designed to ensure that the devices function together and last longer on battery power. Various frameworks balance the transmission distance, data volume, speed, power consumption, and robustness. Refrigerators commonly have sensors for weight, temperature, and humidity, as well as cameras. These sensors can be used to estimate the duration of food preservation, prevent frozen foods from sticking, and illuminate the interior. Open-source software, initiatives to standardize, and platforms such as SmartThings make it easier for appliances, plug-ins, and remote controls to work together.

Things to Think About for Quality Assurance and Compliance

The Food and Agriculture Organization of the United Nations (FAO), Global Cold Chain Alliance (GCCA), and World Health Organization (WHO) all stress the importance of maintaining food at the right temperature for the right amount of time to keep it fresh. Following both general and industry-specific laws is also very important for improving food quality throughout the cold chain 5. These rules are likely to become harsher, especially regarding food safety, data security, and energy use. ISO 22000 (Food Safety Management), Hazard Analysis and Critical Control Points (HACCP), Shelf Life Labels (PPP, First and Best Before), and general energy standards (ISO 50001, ISO 50005, ISO 50006, EN 15232) are some of the groups that set standards for food products, refrigeration equipment, and the cold chain in general.

THINGS TO THINK ABOUT FOR THE ECONOMY AND THE ENVIRONMENT

Smart technology designs that prioritize convenience and sustainability either receive mixed reviews or are completely ignored by the public. These contradictions keep coming up when people talk about

how to store food in a world where climate change and waste reduction are major problems. The total cost of ownership of a smart refrigerator is the sum of the purchase price and operating cost over 12 years. For a conventional appliance, the sum of the purchase price and operating cost is over 16 years. Since 1990, greenhouse gas emissions from Germany's electric power sector have decreased because coal use has decreased and the share of renewable energies has increased. This has led to more interest in the "lifecycle emissions" of collaborative projects like the "Life Cycle Assessment of Smart Appliances" project, which considers significant differences between regions.

Total Cost of Ownership

Appliances are important for food storage, safety, cleanliness, and consumer health. Refrigeration prevents the breakdown of nutrients and stops the growth of germs. The overall cost of ownership of smart refrigerators (purchase, installation, maintenance, and energy) is still unknown, as is their economic viability. Energy expenses reflect both device efficiency and the energy source used. Overall emissions include the making, moving, installing, using, and disposal of equipment.

Smart fridges help the environment by reducing waste and supporting sustainability through better inventory management, monitoring, and temperature control. Keeping track of goods that are underused or spoiled helps people make better buying decisions, which extends the shelf life of food and reduces the environmental impact of making and transporting food.

Sustainability and Emissions Over the Course of a Product's Life

Smart refrigerators can help reduce food waste by allowing people to manage food safety and quality from home. Food spoilage is a major problem worldwide. It not only costs money but also hurts the environment in many ways, such as through emissions from transportation, energy, packaging, and land use. Most traditional methods do not retain detailed records of items and their conditions, which may lead to food being left behind or stored incorrectly. Smart technologies that can automatically monitor things and provide people access to information can assist in reducing spoilage rates by providing people with greater knowledge to make decisions.

There are no formal rules or criteria for smart appliances, which makes it difficult to set standards for their performance and ease of use. General safety requirements may lead manufacturers to modify the standard ranges of low-temperature, hot-water, and humidification functions, considering the inherent sensitivity of perishable goods in various contexts, as outlined in standards such as ISO 22000, ISO 9001, and ISO 14000. Policies on systematic inventory, procurement, and redistribution flows can also be based on larger plans to reduce waste and pollution. The use of these interconnected methods may help prevent early spoilage.

When considering the overall sustainability of a smart refrigerator, three main factors come into play: the materials used to manufacture it, the energy it consumes while operating, and the possibility of reusing or recycling major parts after the model has reached the end of its life. Other factors include construction and maintenance costs. A survey showed that almost 40% of people would still be willing to buy new smart units even if they cost significantly more. The main reasons are that they expect better food safety and quality management throughout the supply chain and better advice on how to buy food.

TRENDS IN THE MARKET AND HOW PEOPLE ARE USING IT

A 2022 study indicated that 40% of the people surveyed were willing to buy smart refrigerators. This shows that there are many opportunities for people to modify their behavior and buy them. Trust in manufacturers, systems, and data governance became important characteristics that affected interest; perceived value and alignment with food-related priorities also had a role in the desire for connected equipment. The chances of widespread use rely on how well manufacturers compete, how well hardware and standards work together across platforms, and how well they fit together with the larger food ecosystem. Improved interoperability and integration may thus promote the adoption of equipment

that provides data-driven insights into the best storage of perishable items and enhance connections within food supply chains.

Demand From Consumers and Changes in Behavior

When technologies promise to change ordinary routines in significant ways, people may not trust them enough to use them immediately. Understanding how customers decide whether to accept new technologies can help tech developers create products that address consumer problems. Smart refrigerators and other technological solutions that provide consumers with much-needed assistance can motivate people to use them by making their behavior more connected and integrated. To make these kinds of connections, it is necessary to understand what affects how people respond and how well the new technology meets their needs.

The demand for different technologies showed that people are much more interested in those that they think would give them value than those that fit with new trends. When consumers trust the companies that make the products and see the brand as open, they are more likely to use technology that promises better food safety, including tracking detailed expiration dates. New smart refrigerators that can manage large-scale household food storage fit into the value-centered paradigm. These larger, value-driven solutions can connect more deeply to wider food supply ecosystems and work with other new ideas and rules in the food safety business simultaneously. Smart refrigerators also create more demand in ecosystems that are still developing but are becoming more popular by solving common problems for consumers. When a broad and deep understanding of potential advances at the systems level is combined, as was done for smart refrigerators, there is a great way to evaluate new technology.

The likelihood of consumers using linked technology depends on how valuable they think it is to solve common problems that consumers have. Existing insights elucidating the origins of consumer-perceived value, trust in manufacturers, brand transparency, and the demand for additional support in challenging areas offer supplementary context for assessing smart refrigerators and other technologies in analogous high-presence activity sectors, such as food and cooking.

Alignment of Ecosystems, Standards, and Competition

The use of smart refrigerators has effects on technology, shopping, government, and business policies. People may be more likely to use these kinds of devices since they are easy to use but worries about data privacy and security could stop people from using them. Therefore, monitoring the effects of demand, competition, and standards on each other helps create models for predicting how many people will buy something.

People have different opinions on smart refrigerators. There is interest in features that help manage the environment and provide logistical support, but surveys show that not many people know about or understand them. Limited acknowledgement of user-centric advantages, despite a substantial rate of overall technology adoption, could impede progress and necessitate considerable time to overcome. People are still willing to utilize similar technologies as long as certain requirements are met, but conditions that are seen as burdensome have a significant negative effect on technological readiness. Tracking meal quantities and ensuring that they can be traced are the most common ways to introduce them in certain situations.

When it comes to consumers, different manufacturers have different competitive positions, and features and ecosystems fit together differently. The fact that the approach is divided into six areas—temperature warning, inventory management, freshness assurance, real-time data provision, recipe coordination, and food acquisitions shows that the company wants to follow the new private standards. Smart refrigerators seem to be the least common type of platform inquiry, but they nonetheless follow the same rules that apply to other platforms. When considering devices and solutions, connectivity stands out as an important factor. The demand for universal connectivity promotes compatibility across larger platforms, although challenges to data silos persist at the level of individual devices.

PROBLEMS, DANGERS, AND LIMITS

Smart refrigerators can make food safer, reduce waste, and make eating more environmentally friendly. To make it easier for people to use, policies and educational incentives are needed in many areas, such as rules that ensure safe operation, guidance that encourages responsible user behavior, and standards that make it possible to utilize the technology in different ways. Smart refrigerators can help reduce waste and spoilage; however, their future role remains unclear. Safety issues and a lack of knowledge could prevent people from adopting, even though they are becoming more concerned about sustainability. Integrating into larger storage ecosystems would provide more features, but it would also mean that systems would need to work together better. A better AI would also make predictions about due dates, the reliability of temperature logs, and changeover times more accurately, which would help consumers even more.

For any significant rollout of interconnected food storage systems, especially those that use learned consumer behavior and data that link content with public supply systems ¹, it is important to follow safety, privacy, and energy rules. The proposed best practices would help families, technicians, and stores learn how to install, set up, and maintain things correctly so that they work safely. We still do not know how fast and in what way consumers will accept the product. The next step of research should look at how willing people are to adopt it, what common barriers exist, and what techniques may be used to build trust in its reliability and value.

Risks to Privacy and Security

A vibrant smart home device ecosystem makes life easier by automatically tracking inventory and managing spoilage. However, this ease of use comes at a cost, especially regarding privacy. Smart refrigerators and other household items can collect sensitive data that can be misused or shared with other people by mistake. Because people are more aware of data privacy, many people are still unsure about smart gadgets, and it is still very important to have the right frameworks in place to protect their data.

Smart refrigerators are both valuable assets and information gateways; therefore, they must deal with contradictory demands in this environment. Expanding interoperability improves the functionality of smart home devices and provides more information; however, it also comes with significant hazards because they live in many smart home ecosystems. Therefore, bridging these needs is a top priority. Design choices can assist in alleviating privacy concerns while ensuring that systems work together and give users control over the information they share.

Data Silos and Interoperability

Smart refrigerators can fail because of the excessive number of software platforms that do not work together or because they depend excessively on one source. Connected living is something that refrigerator manufacturers have mostly ignored, even though cross-device interoperability is a big part of the Smart Home world. The situation has worsened because of the rise in many software programs and the lack of coordination between different technologies that are competing with each other. Smart refrigerators have evolved from simple tools for maintaining food at the appropriate temperature to complex tools with significant effects on food safety and waste. This means that it is more important than ever for devices, manufacturers, and third-party platforms to connect with each other.

Platform fragmentation is a major problem for smart refrigerator integration because it limits the number of devices and services that can be used and makes it difficult for different vendors and domains to work together. The most thorough way to integrate smart kitchens across domains might be to focus on standardized food inventories, including standardized coding for food items, zoning and cataloguing food items and their links to recipes, and smart integration of procurement, distribution, and logistics.

Concerns About Reliability and Maintenance

Smart refrigerators have problems that can shorten their lifespan and make them less valuable. The International Confederation of Household Appliances Manufacturers states that the typical life of a

refrigerator is approximately 15 years. However, as more appliances become connected, people may be more likely to replace older appliances sooner. In addition, smart technologies make it possible for software-based vulnerabilities to exist that are not present in devices that are not connected, such as malware infestations or the hijacking of built-in webcams. People may want to stay away from these types of hazards, or they may want a product that has been tested and confirmed to work. Both tendencies make things riskier for manufacturers: customers may not act if they are not sure that smart features will add value.

Longer support lifetimes are also required for firmware updates. A manufacturer that stops releasing updates after five years, which is frequent in consumer electronics, could make a connected appliance unstable, insecure, or unable to work with new platforms. This could make people think that the extra features are not worth the extra cost. These types of things can be especially crucial for home refrigerators, which tend to remain in one spot longer than other appliances. This means that ambiguity regarding their value lasts longer. Even with the biggest makers of general-purpose gadgets and appliances, there is still a risk that support will decline. Companies that want to enter the market may have a hard time delivering the same level of ongoing support.

POSSIBLE FUTURES AND RESEARCH PATHS

In the last few years, the use of Smart Home Devices has grown quickly, and trends show that an increasing number of these devices will support linked living. Smart refrigerators are an advanced type of home refrigerator that uses sensors, the Internet, AI, and energy efficiency to improve their performance. As these features improve, Smart Refrigerators will change in ways that will make food safer, reduce waste, and help you choose the best method to store food. As technology improves, food emissions decrease, but these reductions will not be as effective until people grasp the policies and behaviors that affect them in their particular situations.

There has been a lot of scholarly interest in smart refrigerators and the technologies that go along with them; however, there are still many gaps in literature. Future research across all dimensions will enhance the comprehension of Smart Refrigerators and their effects on food preservation. Consumers and regulators are concerned about stopping food from going bad and ensuring that food safety rules are followed. Better tracking of storage conditions and more accurate predictions of quality could greatly accelerate the process of reaching both goals. These gains might also trickle down to lower waste at distribution locations farther down the line.

Research priorities include enhancing the precision of temperature logs and spoilage time estimations, guaranteeing resilience during network failures, and optimizing the accessibility of food status information. New research shows that consumers typically have trouble understanding real-time quality assessments, and most refrigerators are dark most of the time, which makes it harder to perform vision-based evaluations.

Connecting to Smart Kitchens and Food Supply Networks

Smart refrigerators can be part of a larger system that includes smart kitchens and food supply networks. This makes it easier to keep track of what you have at home and regulate how you obtain and send food. These scenarios are based on how smart refrigerators collect data on inventory and demand and are in line with new AI technology that helps process perishable commodities.

Smart kitchens in homes are systems that keep track of food stocks in refrigerators, pantries, and cupboards, track the amount of food used against recipes, and predict demand. This information helps people decide what to buy. Automatic reorder workflows may enable full automation when certain conditions are met. In contrast, transparent systems only inform users when they need something and suggest actions without actually doing anything. Food supply chains, on the other hand, can use the information obtained by smart kitchens to change how they distribute goods in real time. They are

considering the use of more sensors and trackers in all phases of manufacturing, transportation, and retail. These possibilities are part of the bigger trend of people "living off the land" and the new idea of PREDICT as a Service.

Progress in AI for Goods that Go Bad

Refrigerators utilize a lot of energy, accounting for approximately 30% of a home's energy utilization. Their main job is to keep food fresh but connecting them to smart homes can make them even better at preserving food. Therefore, providing them with more tools to manage efficient preservation has a lot of room for expansion.

Perishable goods can only be stored for a short time, and their safety, quality, and waste reduction depend on strict temperature control. Although digitization can make monitoring easier, keeping homes cool remains a problem. Therefore, modularity must be considered carefully to avoid replacing appliances too soon. It is important to have features that provide more control over the storage environment and ensure that new appliances work with older ones. There is little research on artificial intelligence in the food industry. To make food safer and reduce waste, we need to be able to forecast how long it will last or which foods should not be mixed based on current inspections. Food with partial status also needs to be considered carefully; it does not just mean "good" or "bad."

POLICY, STANDARDS, AND TEACHING CUSTOMERS

The idea of a "smart kitchen" where appliances work together to keep track of food, buy it, cook it, and eat it is appealing. Smart refrigerators are a significant part of this, but not many people use them worldwide. Over 700 million units are shipped each year, but only 20 million smart models are currently in use. Policy, standards, and consumer education are all very important for ensuring that the new smart refrigerator market fits with a future vision of linked life across the supply chain.

The switch to a smart-connected life in all areas is being driven by rapid climate change and resource loss. Global food waste harms the economy and environment more than it helps. With more than 1.3 billion tonnes of food going to waste at stores and homes, we need devices that help keep food fresh by monitoring it, providing feedback, sending alarms, and offering rewards. Smart-connected refrigerators use sensors, cameras, and machine learning to learn about spoilage risks, quality loss, inventory, open-door events, and other factors that affect a wide range of metrics on perishable goods.

Rules and Regulations and Following Them

Smart refrigerators have a specific purpose, but they also enable the connection of more systems to each other. The refrigerator might be the center of the kitchen ecosystem, connecting to home energy management systems and utilities and adding things like meal planning and grocery shopping. Research on how to improve storage duration and climate for perishable foods to make them last longer strengthens this link.

The refrigerator's connection to outside food supply networks produces feedback loops that help consumers make decisions and affect what stores offer. To reach these goals, forecasts of shelf life and safety quality affect choices about what to buy, when to buy it, and how long to store it. Temperature and humidity histories help with adaptation and compartment selection.

Improvements in the accuracy, fault tolerance, and latency of forecasts in artificial intelligence for perishable items support features such as real-time analytics, flexible operating modes, and machine-learning-based shelf-life estimates for packaged foods.

The development of smart refrigerators is similar to other breakthroughs, such as electric ovens and microwaves. Changes in cooking speed and ease affect how people cook. The pandemic in 2020 made people more mindful of food safety, storage, and hygiene. The World Health Organization states that food temperatures should remain within safe ranges.

The right technology must be available for smart refrigerators to be added to kitchens, for temperature logging to work, and for rules to be adhered to. People's interest in feature suites is based on how they behave as consumers, and how they save, protect, clean, and dispose of data affects the availability of information for predictive modelling. It is still very important to teach people about food safety, safety risks, and how to protect themselves from foodborne diseases.

Possible regulations, standardization, and instructional efforts encourage people to use smart refrigerators to keep food safe and reduce waste. To create a good environment for appliances to deliver their potential for social good, we need to ensure that technology and policy work together to keep things easy while also addressing safety, security, interoperability, and sustainability, as well as new areas of research.

Food safety and waste reduction are two of the most important considerations in many fields. Information about temperature and humidity histories, how these factors affect food products, and shelf-life estimates meets consumer needs. This helps them follow safety guidelines and supports attempts to extend the life of food after purchase.

Rules For Safe and Long-Lasting Use

Fridges are very important for keeping food safe, and they need to work all the time and be trustworthy for the safety of the user. Smart refrigerators, especially those that can be monitored from afar, naturally make people worry about their use. Therefore, when selling something, there must be explicit rules about how to install, operate, care for, and keep an eye on it. These rules should be applied to consumers, technicians, and retailers. Smart fridges have a lot of potential to reduce food waste using data-driven insights. The rules that follow also cover crucial compliance requirements, with sanitation, monitoring, and expiration tracking being the most important aspects.

Hygiene, integrated monitoring, and continuing education are all parts of basic good practices. Dedicated monitoring systems provide useful information; however, they should not replace frequent checks of important things, such as the cooling cycle or overall cleanliness. When monitoring is performed through a mobile application, a clear, easy-to-find summary of the system's status, such as whether the cooling cycle is working, how clean it is, whether air is being vented, whether moisture is present, and whether items are coming in or going out, makes it easy to check things on-site quickly and efficiently. Temperature information should be periodically downloaded. It is also important to monitor the cold chain before installation. During the entire usage phase, devices should be managed, monitored, and properly handed over. There should be a clear sharing of any detailed information about the system, such as the curriculum, instructive film, or specification sheet.

CONCLUSION

Smart refrigerators are becoming an important part of the twenty-first-century concept of smart kitchens; however, some areas have not been fully explored. There are many ways to expand research into the future of these appliances. For example, researchers could investigate how to make them work better with larger smart kitchen systems, how to formalize and expand academic knowledge of how they work with digital food supply chains, how to use advanced artificial intelligence algorithms to improve decision support and predictive capabilities, and how to include recommendations on food storage and shelf life in the design of the products. These pathways are not only of technological significance but also have broader implications for comprehending how smart refrigeration will redefine the function of this equipment in society and the goal of mitigating spoilage and food waste long after acquisition.

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