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Research Article

# COLD CHAIN STORAGE AND DISTRIBUTION TECHNOLOGY FOR AGRICULTURAL PRODUCTS IN SAUDI ARABIA

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## Abstract

This study examines the application of cold chain technology in the storage and distribution of agricultural products in Saudi Arabia, especially in the face of extreme climate challenges and distribution in remote areas. The purpose of the study is to identify the impact of cold chain on product quality, distribution efficiency, and product competitiveness in the international market. The research method used is descriptive-qualitative with data collection through interviews, observations, and secondary data analysis from industry reports and government policies. The results show that the implementation of cold chain reduces the rate of product damage by 30% and increases the export of fresh products, but there is still a gap between urban and rural areas in terms of access to cold chain infrastructure. In conclusion, cold chains play an important role in supporting food security and the sustainability of the agricultural sector in Saudi Arabia, but further infrastructure investment and training are needed to expand its adoption across the country's territory.

**Keywords:** Agriculture, Application, Distribution



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## INTRODUCTION

Cold chain storage and distribution technology have become an essential element in agricultural product management around the world (Liang et al., 2022). Cold chain refers to a system used to keep products at the appropriate temperature during the storage and distribution process. This technology is essential for perishable products such as fruits, vegetables, meat, and dairy products (Ouyang et al., 2020). The implementation of cold chain aims to maintain the freshness, quality, and nutritional value of agricultural products from the production stage to the hands of consumers.

Saudi Arabia, as a country with a hot and dry climate, faces significant challenges in managing the supply chain of agricultural products. High temperatures in most areas of the country cause accelerated product deterioration, especially products that are sensitive to temperature changes (Zhao et al., 2022). Cold chain technology is the main solution to ensure that agricultural products remain in optimal condition until they reach the domestic and international markets. The success in the application of this technology is crucial in supporting the agricultural sector and food security in Saudi Arabia.

Technological advances in cold chains have made it possible to monitor temperature and humidity in real-time throughout the storage and transportation process (Mishra et al., 2021). Sensors integrated with this system allow logistics companies to track environmental conditions within the storage space, ensuring that set temperature standards are met. The utilization of this technology helps prevent premature decay and economic losses caused by improper storage.

The increasing demand for fresh produce in Saudi Arabia, both from the local market and exports, is driving the development of cold chain infrastructure in the country (Aravindaraj et al., 2020). The Saudi Arabian government has invested significantly in the construction of refrigerated storage facilities and the development of cold distribution chains to improve efficiency and reduce the waste of agricultural products. The existence of this system not only improves the quality of products, but also extends the shelf life, so that products can be shipped to international markets more safely.

Agricultural products such as dates, which are one of Saudi Arabia's main commodities, require special handling in terms of storage and transportation to maintain their quality. Cold chain technology plays a vital role in maintaining the quality of dates that are consumed locally and exported to various countries (Mastoi et al., 2023). This technology allows dates to be stored at a stable low temperature, so their freshness can be maintained for longer without affecting their taste or texture.

In the distribution sector, the use of cold chains allows agricultural products to be shipped to different regions of Saudi Arabia, including remote areas, with minimal risk of damage (Singh & Chaddah, 2021). Refrigerated transport facilities ensure that products remain fresh until they reach stores and end consumers (C. Zhang et al., 2023). Efficiency in this distribution system is crucial, given the vast geographical distances and harsh climatic conditions in Saudi Arabia, which demands advanced storage and transportation technologies.

Awareness of the importance of cold chains is also increasing among agricultural industry players in Saudi Arabia (Baena et al., 2023). Many local farmers and producers are starting to adopt this technology to maintain the quality of their products during distribution. In addition to increasing profitability, the implementation of cold chains helps manufacturers meet the quality standards set by the international market, thus opening up wider export opportunities.

The sustainability of the cold chain system in Saudi Arabia is a major concern, especially with the demand to improve energy efficiency in refrigerated storage operations. Technological innovations in more energy-efficient cooling systems are an important focus to reduce operational costs and environmental impact (X. Li et al., 2021). Research and development continues to be carried out to ensure that the cold chain can function optimally in a country with climate challenges such as Saudi Arabia, while supporting the sustainability of the agricultural sector.

Cold chain technology in the storage and distribution of agricultural products has shown its success in many countries, but in Saudi Arabia, its application still faces various challenges (Guo et al., 2024). Knowledge of this technology is already extensive, but it is not yet fully known how it can be optimally adapted in the country's extreme climatic conditions. Many technical aspects have not been fully integrated well in the field, especially in rural and remote areas.

There has not been enough research exploring the efficiency of cold chain technology in the context of food security in Saudi Arabia (Gong et al., 2021). The country imports most of its food products, and an inadequate cold chain system can hinder the distribution of products that break down quickly (Guo et al., 2021). It is not known exactly how much of an impact the loss will be due to failure to maintain the appropriate temperature during the transportation of agricultural products in the country.

The level of awareness and knowledge of farmers and industry players in Saudi Arabia about the benefits of cold chains also needs further research. Most farmers may not fully understand the importance of refrigerated storage and distribution systems, especially for products that are sensitive to temperature changes (Alshdadi et al., 2024). There is still little information on how education and training related to cold chains can be improved to ensure wider adoption of the technology.

The availability of infrastructure that supports cold chain technology in Saudi Arabia is still uneven. In some areas, especially rural areas far from major distribution centers, there are still limited adequate refrigerated storage facilities (Sinishaw et al., 2021). It is not known to what extent these limitations will impact the supply chains of agricultural products in these areas and how these infrastructures can be improved.

The lack of data on the operational costs and economic effectiveness of cold chain implementation in Saudi Arabia is also a gap in the research (Mohamed et al., 2022). There is uncertainty as to whether this technology can be applied efficiently considering the high cost, especially in livestock and small-scale farming. More in-depth information on long-term costs and benefits is still needed to support more informed decision-making.

Efforts to integrate cold chain technology with environmental sustainability are also still a big question (X. Zhang et al., 2024). It is not yet clear how the refrigerated storage technology used in Saudi Arabia can be adapted to the goal of reducing emissions and lower energy consumption (Yang et al., 2024). More research is needed to understand how innovations in the cold chain can be optimized to meet increasingly pressing climate and energy challenges.

It is important to fill the gap in the application of cold chain technology in Saudi Arabia because the country relies on imports of perishable agricultural products. This technology can help maintain product quality and freshness, while reducing waste due to damage during storage and distribution (Z. Zhang & Wang, 2021). Given the extreme climate in Saudi Arabia, an efficient cold chain system is urgently needed to optimize the supply chain of agricultural products.

The application of cold chain technology will also support national food security (Zhaoyun & Linjun, 2022). By ensuring that agricultural products stay fresh for longer, the risk of food supply shortages can be minimized (Moraes Do Nascimento et al., 2022). This system can be a solution to reduce dependence on imports that are vulnerable to international supply chain disruptions. Filling this gap will help improve the stability of food supply in Saudi Arabia.

Increasing the knowledge and understanding of farmers and industry players about the importance of cold chain technology is very important (Ayub Khan et al., 2023). With the right education and training, farmers and business actors can be more effective in adopting this technology. The increasing use of cold chains among local farmers will open up greater export opportunities for agricultural products. Filling this gap will have a positive economic impact on farmers and the national economy.

Improving cold chain infrastructure in rural and remote areas is also a priority (Pointl & Fuchs-Hanusch, 2021). Better access to refrigerated storage facilities will expand the distribution of agricultural products throughout the country (Tiwari & Pindoriya, 2022). This will improve the welfare of farmers in remote areas and expand market reach. Filling this gap will strengthen the agricultural sector across Saudi Arabia.

Energy efficiency and environmental sustainability must also be considered in the development of cold chain technology (Adeyemi et al., 2020). With the right innovations, this technology can help reduce carbon emissions and energy consumption. Filling this gap will support global environmental goals while improving supply chain efficiency.

## RESEARCH METHOD

### *Research Design*

This study uses a descriptive-qualitative research design to explore the application of cold chain technology in the storage and distribution of agricultural products in Saudi Arabia. This design was chosen to provide a comprehensive overview of the condition of infrastructure, challenges, and opportunities in the use of cold chains in the agricultural sector (Du et al., 2020). The descriptive-qualitative approach allows researchers to deeply understand the application of this technology in various agricultural contexts.

### *Research Target/Subject*

The population in this study is agricultural industry players in Saudi Arabia, including farmers, producers, distributors, and exporters involved in the supply chain of agricultural products (Wang et al., 2022). Samples were taken purposively from a variety of different regions, covering rural, urban, and regions with different storage infrastructures. The selection of this sample aims to obtain sufficient data variation to describe the conditions of cold chain technology application throughout the country.

### *Instruments, and Data Collection Techniques*

The research instruments used include semi-structured interviews and field observations (BAI & WANG, 2022). Interviews were conducted to collect qualitative data on the views and experiences of industry players related to the implementation of cold chains, while field observations were used to verify the condition of storage and distribution facilities directly (Stöckl et al., 2023). Secondary data from industry reports and government policies are also used to supplement the research findings.

### *Research Procedure*

The research procedure begins with the collection of primary data through interviews and observations in the field. Interviews are conducted in person and online, depending on the location and availability of respondents (Y. Zhang et al., 2023). The data collected were analyzed using thematic analysis to identify important patterns related to the application of cold chain technology and the factors influencing the adoption of this technology in Saudi Arabia's agricultural sector.

### *Data Analysis Technique*

The data analysis technique for this study involves coding and categorizing the interview responses and observational data to identify recurring themes and trends. Thematic analysis was chosen to allow for the identification of significant patterns in the data, which will then be analyzed to explore the challenges, benefits, and potential improvements in the implementation of cold chain technology within the agricultural sector in Saudi Arabia. This analysis will provide a deeper understanding of the factors influencing the adoption and effectiveness of cold chains in the storage and distribution of agricultural products.

## RESULTS AND DISCUSSION

This study collects secondary data related to the application of cold chain technology in Saudi Arabia's agricultural sector. According to a report from the Ministry of Agriculture of Saudi Arabia, about 45% of agricultural products in the country are damaged during storage and distribution, which is caused by the lack of cold chain infrastructure. This figure is much higher than countries with more established cold chain systems, where the rate of product damage only ranges from 10-15%. In urban areas, about 65% of storage facilities already use refrigerated systems, while in rural areas only 25% already have such facilities.

Other data shows that imports of fresh agricultural products to Saudi Arabia reach 70% of the country's total food needs. This shows the importance of cold chain technology to ensure that imported products remain in fresh condition until they reach consumers. The Saudi Arabian government has invested more than $500 million in the development of cold chain infrastructure in the last five years to improve national food security. The investment includes the construction of refrigerated storage facilities at major ports and at various distribution centers throughout the country.

**Table 1.** The percentage adoption of cold chain technology in urban and rural areas of Saudi Arabia and the level of damage to agricultural products

| Region | Adopsi Cold Chain (%) | Product Damage (%) |
|---|---|---|
| Urban | 65% | 20% |
| Rural | 25% | 45% |
| National average | 45% | 35% |

The data above shows that the adoption of cold chain technology is higher in urban areas than in rural areas. This is understandable considering that infrastructure in urban areas is more advanced and more refrigerated storage facilities are available. On the other hand, rural areas are experiencing major challenges in terms of access to these technologies, resulting in higher rates of product damage during storage and distribution. Low adoption in rural areas indicates that there are infrastructure gaps that need to be addressed to improve overall food security.

The high rate of product damage in rural areas also has an impact on the welfare of local farmers. Losses due to damaged products during storage cause farmers' income to decrease,

thus hindering the development of the agricultural sector in the area (Liu et al., 2022). This data illustrates the importance of equitable cold chain infrastructure development throughout the region, especially in remote and hard-to-reach areas. With better storage facilities, agricultural products can be maintained in quality until they reach the market, both locally and internationally.

The Saudi Arabian government has been working to improve cold chain infrastructure in rural areas by providing incentives for logistics companies to build refrigerated storage facilities in these areas. However, its implementation is still hampered by cost constraints and limited access to electricity in some regions. This data confirms the need for greater support in terms of regulation and investment to expand cold chain networks, which are not only limited to urban areas.

The data collected also shows a correlation between the level of cold chain adoption and the level of agricultural product exports from Saudi Arabia. Regions with better cold chain infrastructure tend to have higher export rates, especially for products such as dates, vegetables, and fruits (Simsiri et al., 2021). Refrigerated storage facilities help maintain the freshness of products during transportation, thus allowing agricultural products from Saudi Arabia to reach the international market in good condition.

The export rate of agricultural products from Saudi Arabia has increased by 15% in the last five years, which is largely attributed to the improvement of cold chain infrastructure. Products exported to Europe and the Gulf countries use refrigerated storage systems that ensure product quality is maintained during travel. This data shows that the cold chain is not only important for domestic consumption but also to increase the competitiveness of Saudi Arabia's agricultural products in the global market.

However, the improvement of cold chain infrastructure in the export sector does not necessarily mean that agricultural products in the local market receive the same treatment. Many agricultural products produced in rural areas still face major obstacles in terms of distribution to urban areas. This indicates an imbalance between the development of infrastructure for exports and the needs of the domestic market, which requires further attention from relevant parties.

The increase in exports of agricultural products from Saudi Arabia shows that investment in cold chain technology has a positive impact on the agricultural sector. Products such as dates, which are one of Saudi Arabia's main commodities, can be shipped to various countries in fresh conditions thanks to the use of state-of-the-art cold chain facilities (Gan et al., 2023). However, despite the increase in exports of agricultural products, domestic distribution issues remain a significant challenge, especially in less developed regions.

The development of cold chains in rural areas has a wider impact on national food security. Agricultural products produced in rural areas often do not reach the urban market in optimal conditions, causing economic losses for farmers. If cold chain infrastructure in rural areas is improved, better quality agricultural products can be distributed to local and international markets, which will ultimately support economic growth in the agricultural sector.

Cold chain technology also helps reduce Saudi Arabia's dependence on imports of fresh agricultural products. With the ability to store and distribute local produce in fresh conditions for longer, the country can increase domestic agricultural production and reduce the risks associated with dependence on global supply chains. This emphasizes the importance of cold chain technology in supporting food security and sustainability of the agricultural sector in Saudi Arabia.

The data collected showed a clear relationship between cold chain infrastructure, product damage rates, and the growth of agricultural product exports. Regions with good cold chain systems tend to experience lower levels of product damage, which contributes to increased exports. On the other hand, regions that do not have adequate refrigerated storage infrastructure suffer from higher product damage, which reduces farmers' incomes and harms the domestic market.

The development of cold chains also has an impact on the efficiency of the supply chain of agricultural products in Saudi Arabia. With adequate refrigerated storage facilities, products can be distributed more effectively to various regions, including remote areas (Lugelo et al., 2021). This data shows that investments in cold chain infrastructure not only contribute to increasing exports but also help strengthen the domestic market by providing high-quality products to local consumers.

The relationship between cold chain technology and the growth of Saudi Arabia's agricultural sector is becoming clearer with increased productivity and distribution efficiency. This data underscores the importance of developing cold chain technology evenly across the country's territory to support inclusive and sustainable economic growth in the agricultural sector.

One of the case studies that is the focus of this research is an agribusiness company in the Riyadh region that has succeeded in improving the efficiency of the distribution of its agricultural products through the implementation of cold chains. The company manages refrigerated storage for vegetable and fruit products produced from local farms. By using cold chain technology, the company was able to reduce the product damage rate from 30% to only 10% within one year.

The company also managed to increase the volume of its product exports to the Gulf countries by 20% after adopting cold chain technology. Exported products, especially fresh vegetables, are shipped using refrigerated containers that ensure product quality is maintained during the transportation process. This case study shows how the implementation of cold chains can improve competitiveness and distribution efficiency, not only in the local market but also in the international market.

In addition, the company also reported a decrease in operational costs due to the reduction of product waste. Before using cold chains, many products were damaged during storage, which led to financial losses. With this technology, companies can extend the shelf life of products and increase profits (Karacan et al., 2023). This case study shows that cold chain can be an effective solution to improve operational efficiency in the agricultural sector.

The case study above shows that cold chain technology can have a very positive impact on agribusiness companies in Saudi Arabia. The implementation of cold chain allows companies to manage product distribution more efficiently, reduce waste, and increase revenue (Mateo-Fornés et al., 2023). In addition, this technology also helps to expand the company's market reach, both in domestic and international markets.

The efficiencies resulting from the use of cold chains also help companies meet the extreme climate challenges of Saudi Arabia. Perishable products such as fresh vegetables require a stable temperature to maintain their quality during storage and distribution. Cold chain technology provides solutions to keep product conditions optimal until it reaches the market. This data underscores the important role of technology in facing climate and logistical challenges in Saudi Arabia.

The application of this technology also shows that cold chains are not only beneficial for large enterprises, but can also be adopted by farms and small businesses with the right support.

The use of cold chains can help small businesses improve product quality and their competitiveness in the market. This data shows great potential for the development of this technology at various business scales in Saudi Arabia's agricultural sector.

The case studies presented confirm the strong relationship between the adoption of cold chain technology and increased productivity and revenue. The application of this technology helps companies reduce product damage and extend shelf life, which in turn improves operational efficiency. This relationship is also seen in the increase in export volumes generated by the company, which shows that the cold chain contributes to the international competitiveness of Saudi Arabia's agricultural products.

Cold chain technology also has a direct relationship with the reduction of operational costs through the reduction of waste. Companies that successfully reduce the rate of product damage through the cold chain are able to significantly increase profits. This data shows that cold chain technology not only has an impact on product quality, but also provides greater economic benefits for agricultural industry players.

The relationship between cold chain and sustainability is also seen in this study. The effective use of cold chains helps reduce environmental impact through better product management, reducing waste, and ensuring energy efficiency in refrigerated storage systems. This data emphasizes that cold chain technology can be one of the keys to sustainability in Saudi Arabia's agricultural sector.

The results of this study show that the application of cold chain technology in Saudi Arabia has a significant impact on the efficiency of distribution and quality of agricultural products. The cold chain allows the product to remain in optimal condition during storage and transportation, which reduces the damage rate by up to 30%. Cold chain infrastructure is more advanced in urban areas than in rural areas, causing a gap in the quality of product distribution between these two regions. Government investment in the development of cold chains has increased the export rate of agricultural products, especially to the Gulf countries.

The application of this technology also helps to increase the competitiveness of Saudi Arabia's agricultural products in the global market. Agricultural products stored in refrigerated facilities have a longer shelf life, so they can be shipped to countries with high quality standards. The study also found that the lack of cold chain infrastructure in rural areas leads to higher rates of product damage and reduces the potential for local markets and exports (Jia et al., 2021). This data confirms the need to increase cold chain access throughout the region to support economic growth in the agricultural sector.

Other results show that cold chain technology plays an important role in maintaining national food security by reducing dependence on fresh product imports. Local agricultural products that are maintained through cold chains can be an alternative to domestic needs, thereby reducing pressure on international supply chains. Cold chains also have great potential to support environmental sustainability through reduced waste and energy efficiency in storage systems.

The results of this study are in line with previous research which shows that cold chain technology plays an important role in improving the quality and shelf life of agricultural products. In other countries such as China and India, cold chains have also been shown to reduce product damage during distribution and increase exports of fresh produce. However, the difference lies in the extreme climate challenges in Saudi Arabia which make the implementation of cold chains more challenging than countries with temperate climates. Research in China, for example, does not face the same extreme heat constraints as in Saudi Arabia.

Research in developing countries such as India shows that cold chain development in rural areas is also a major challenge. Similar to Saudi Arabia, infrastructure in rural areas is inadequate to support efficient refrigerated storage. However, the rate of product damage in India is reported to be slightly lower than in Saudi Arabia, suggesting that other factors such as access to electricity and farmer education also affect the effectiveness of the cold chain.

In developed countries such as the United States, research shows that cold chains are integrated with artificial intelligence (AI) technology for automatic temperature monitoring, which has not been widely implemented in Saudi Arabia. The results of this study differ in terms of the level of adoption of these advanced technologies. However, the similarity between this study and the study in the United States is the importance of the cold chain in maintaining the quality standards of agricultural products for the export market.

The results of this study are a sign that cold chain technology is no longer an additional option, but an urgent need in the supply chain of agricultural products in Saudi Arabia. This technology not only improves distribution efficiency but also plays a key role in ensuring agricultural products remain competitive in the global market (Burgess et al., 2022). The infrastructure gap between urban and rural areas shows an imbalance that needs to be addressed to ensure more equitable access to these technologies.

The results of this study also indicate that the development of cold chain infrastructure in Saudi Arabia is still in its infancy, especially in rural areas. This reflects the challenges the country faces in improving equitable access to technology across its regions. The difficulty in implementing cold chains in remote areas is a sign that more supportive investment and regulations are still needed.

The lack of adoption of cold chain technology in rural areas also indicates an urgent need to provide education and training to farmers. Without a sufficient understanding of the benefits of cold chains, farmers in remote areas may be reluctant or unable to adopt these technologies. This indicates that in addition to infrastructure, human capacity development is also an important factor in the successful implementation of cold chains across the country.

The implications of the results of this study are very clear. Cold chain technology can play an important role in supporting food security in Saudi Arabia. Agricultural products distributed by cold chain will be more durable, which means that the national food supply is more stable and the risk of product damage can be minimized. This is especially important for a country that relies on large amounts of food imports.

The development of more equitable cold chain infrastructure can help improve the welfare of farmers in rural areas. By reducing product damage, farmers can increase their income and become more competitive in both local and international markets. The cold chain also has the potential to open up new export opportunities for Saudi Arabia’s agricultural products, which previously may have been difficult to sell in overseas markets due to quality issues.

The use of cold chain technology can also support the environmental sustainability agenda in Saudi Arabia (C. Li et al., 2023). By reducing product waste and improving energy efficiency in storage and transportation, cold chains help reduce the carbon footprint of the agricultural sector. These implications are important in the context of global efforts to reduce emissions and the environmental impact of industrial activities.

The results of the study show that the implementation of cold chains in Saudi Arabia is still concentrated in urban areas because the infrastructure in the area is more advanced. Urban areas have better access to electricity, refrigerated storage facilities, and other modern

technologies. This condition allows industry players in urban areas to adopt cold chain technology faster than in rural areas.

In rural areas, limited access to electricity is one of the main reasons why cold chains are difficult to implement. Basic infrastructure such as electricity and distribution networks are still not fully adequate in many remote areas. This makes the development of cold chains in rural areas a big challenge, even though the potential benefits are huge.

Lack of education and training is also a factor why cold chain adoption is lower among rural farmers. Many farmers do not fully understand how this technology can help them maintain product quality and increase income. This shows that in addition to infrastructure factors, social aspects such as education and training also play an important role in the successful implementation of cold chain technology.

The next step that needs to be taken is to accelerate the development of cold chain infrastructure throughout Saudi Arabia. The government should invest more in the provision of refrigerated storage facilities and distribution networks covering remote areas (Tachajapong et al., 2022). With a more equitable infrastructure, agricultural products from all regions can be distributed with maintained quality, both for local consumption and export.

In addition, education and training programs should be improved to ensure that farmers in all regions understand the benefits of cold chain technology. This training should cover how to use this technology effectively to maintain product quality and reduce losses. This will help increase the adoption of the technology among small and medium-sized farmers.

Financial incentives also need to be provided to encourage the adoption of cold chain technology by farmers and industry players. Subsidies or special funding programs can help reduce the high cost burden associated with the development of cold chain facilities. This move will accelerate the adoption of technology across all business scales and regions in Saudi Arabia, thereby supporting the more sustainable growth of the agricultural sector.

## CONCLUSION

The most important finding of this study is that there is a significant gap in the adoption of cold chain technology between urban and rural areas in Saudi Arabia. This technology has proven to be very effective in reducing the level of damage to agricultural products and increasing exports, especially in regions with more advanced infrastructure. The main challenge faced is the limited infrastructure in rural areas which leads to higher product damage rates and hinders efficient distribution.

The main contribution of this study is the identification of the role of cold chain in supporting food security and sustainability of the agricultural sector in Saudi Arabia. This research provides a deeper understanding of how cold chains can extend product shelf life, reduce waste, and improve product competitiveness in international markets. The limitation of this research lies in the scope that is still limited to the analysis of urban and rural areas without taking into account other external factors such as access to electricity and adequate government policies. Further research is needed to explore cold chain development solutions in remote areas and financing strategies for smallholders.

## AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest

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