

Leveraging Industry 4.0 technologies in Canadian agri-food supply chains

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ABSTRACT

The rapid growth of the global population has significantly increased demand for agri-food products, placing substantial pressure on global supply chains. The egg industry, a critical segment of Canada's agri-food sector, faces challenges related to rising consumption and ethical concerns over animal welfare. Eggs are widely valued for their affordability and nutritional benefits, with total sales in Canada increasing by 8.4% in 2023 to \$2.2 billion. However, a major issue in this industry is the annual culling of approximately 22.5 million one-day-old male chicks due to their lack of economic viability, as they neither lay eggs nor reach the required weight for meat production. Addressing these challenges requires an optimized approach to supply chain management and the integration of advanced technologies.

To manage the increasing egg consumption, this study employs supply chain network design as a key optimization tool. A novel mathematical model is proposed to enhance the efficiency of the Canadian egg supply chain by minimizing total costs and improving resource allocation. The model optimizes decision variables such as material flow, partner selection, and transaction values between entities, ensuring a more cost-effective and sustainable supply chain. Animal welfare concerns are addressed through the adoption of Industry 4.0 solutions, particularly by non-invasive, real-time optical sensing technologies, including hyperspectral imaging, spectroscopy, and computer vision. These technologies enable early gender determination before hatching, thereby preventing the birth of male chicks and eliminating the need for culling. Implementing such innovations are expected to enhance ethical standards in hatcheries. This study further examines the economic and operational impacts of adopting Industry 4.0 technologies within the egg supply chain.

A comprehensive mathematical model is developed to assess the cost-effectiveness of integrating non-invasive optical sensing solutions. By optimizing both supply chain tactical decisions and animal welfare strategies, this research enhances economic sustainability while significantly reducing the number of culled male chicks. Overall, this study highlights the transformative potential of advanced technologies in modernizing the egg industry. It is demonstrated that by integrating Industry 4.0 solutions with strategic supply chain optimization, traditional hatcheries can transition into smart, sustainable operations, balancing economic efficiency with ethical responsibility. The findings of the present study indicate that hyperspectral imaging, as a non-destructive optical sensing technology, can reduce poultry losses significantly, providing a new source of table eggs in Quebec, Canada. This could lower dependence on imported and nationally incubated eggs, leading to significant cost savings.