Food loss in the Canadian supply chain

Session 2C

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Land Acknowledgement

- The University of Regina is situated on Treaty 4 lands with a presence in Treaty 6. These are the territories of the nêhiyawak, Anihšināpēk, Dakota, Lakota, and Nakoda, and the homeland of the Métis/Michif Nation. I am grateful for the privilege to learn, teach, and work on Treaty 4 lands.

Buffalo Winter Count Robe, UofR
painted by Elder Wayne Goodwill from Standing Buffalo Dakota Nation

Introduction

- Globally, around 1.18 billion tonnes of food are wasted annually, giving rise to food insecurity and environmental concerns:
  - ❑ ***European Union**: ~88 million tonnes of food waste per year*
  - ❑ ***United States**: ~45 million tonnes of annual food loss*
  - ❑ ***Canada**: ~58% of total food production wasted (~3% of GDP)*

- Food waste in landfills produces methane, contributing about 8% of global greenhouse gas (GHG) emissions

- **Fruits and vegetables** represent the highest losses, contributing around 42% of total food waste
  - ❑ *Poor storage and transport increase spoilage, especially in post-harvest stages*

2030 SDGs

The Canadian government has committed to reducing food waste by 50% by 2030 to meet the United Nations' Sustainable Development Goals.

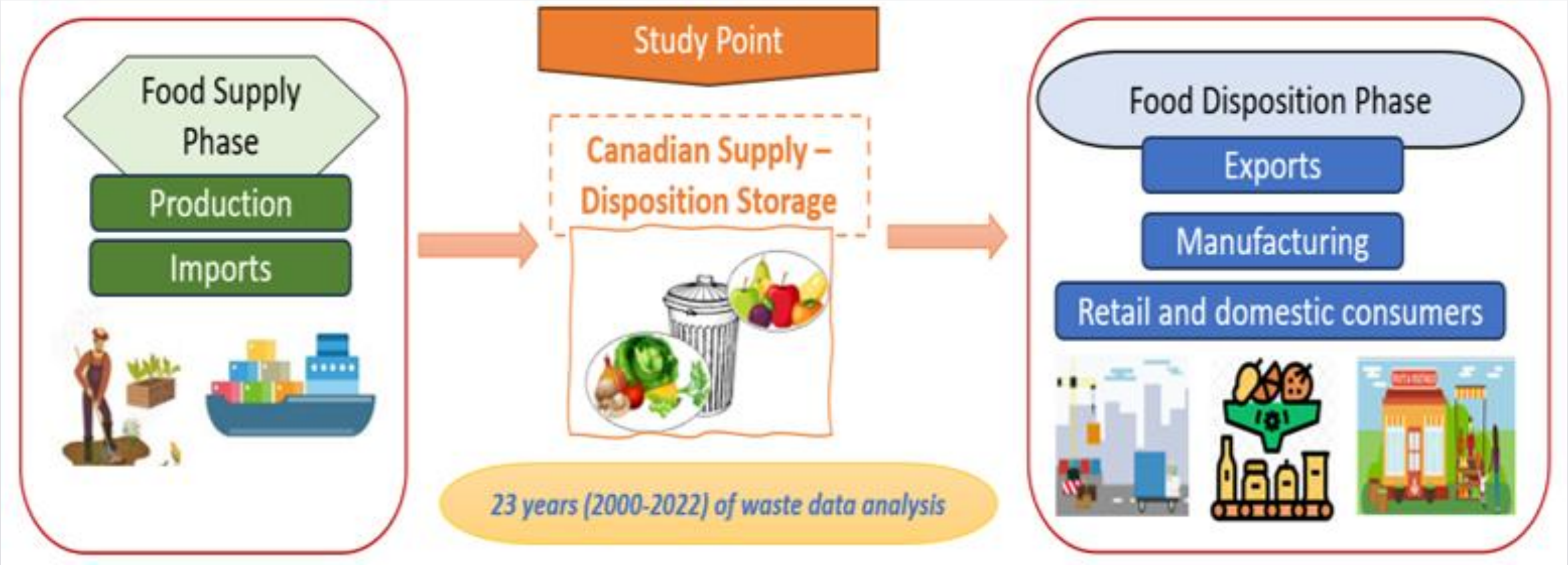
Literature Review

- Food waste quantification is widely recognized as essential for effective waste minimization strategies and policy decisions (Corrado and Sala 2018; De Laurentiis et al. 2018; Li and Roe 2024)
- Existing studies heavily focus on retail and consumer stages, overlooking upstream stages such as production, post-harvest handling, and storage (Liu et al. 2020; Anand and Barua 2022; Caldeira et al. 2021)
- Most research examines consumer behaviour at individual, household, and regional levels (Casonato et al. 2023; Nguyen et al. 2023)
- Significant gap in supply chain-wide trend analysis and predictive modelling, particularly at the **pre-consumer stage** (Hartikainen et al. 2018; Van der Werf and Gilliland 2017)

Objectives

(i) Analyze the waste generation trends for fresh fruits and vegetables at the Canadian supply-disposition storage (=lost or discarded portion of food quantities during processing or storage)

(ii) Develop predictive models to quantify food waste generation using regression analysis



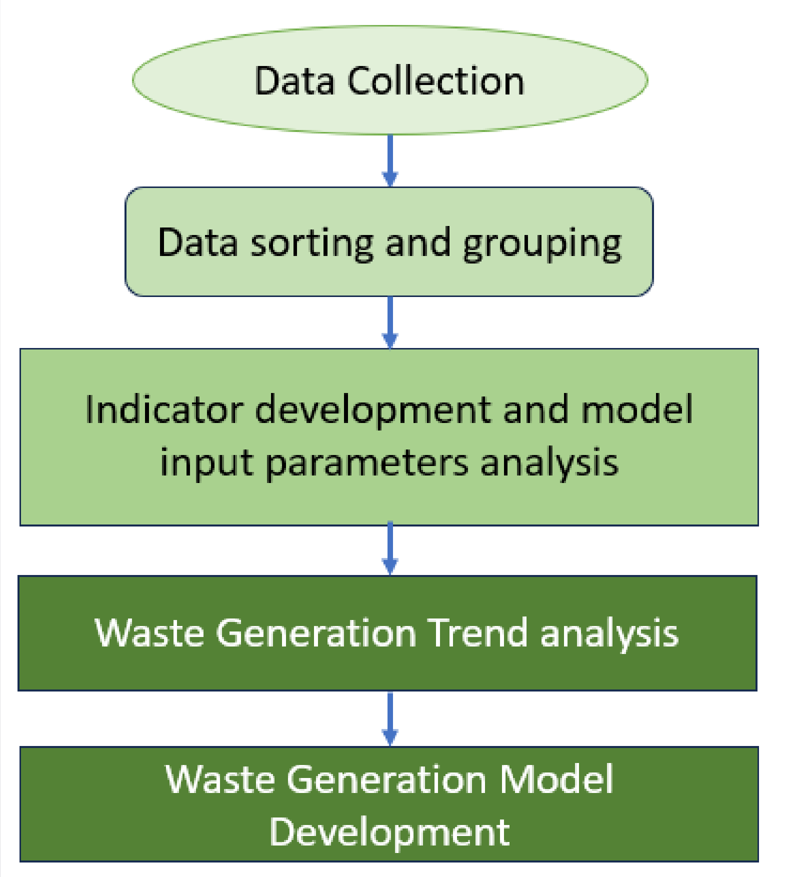
Category 1: **Fresh Fruits** (31)

- Apples, oranges, grapes, kiwis, apricots, watermelons, pears, peaches, cherries, etc.

Category 2: **Fresh Vegetables** (33)

- Carrots, broccoli, cabbage, spinach, celery, corns, eggplants, peas, garlic, etc.

Methodology



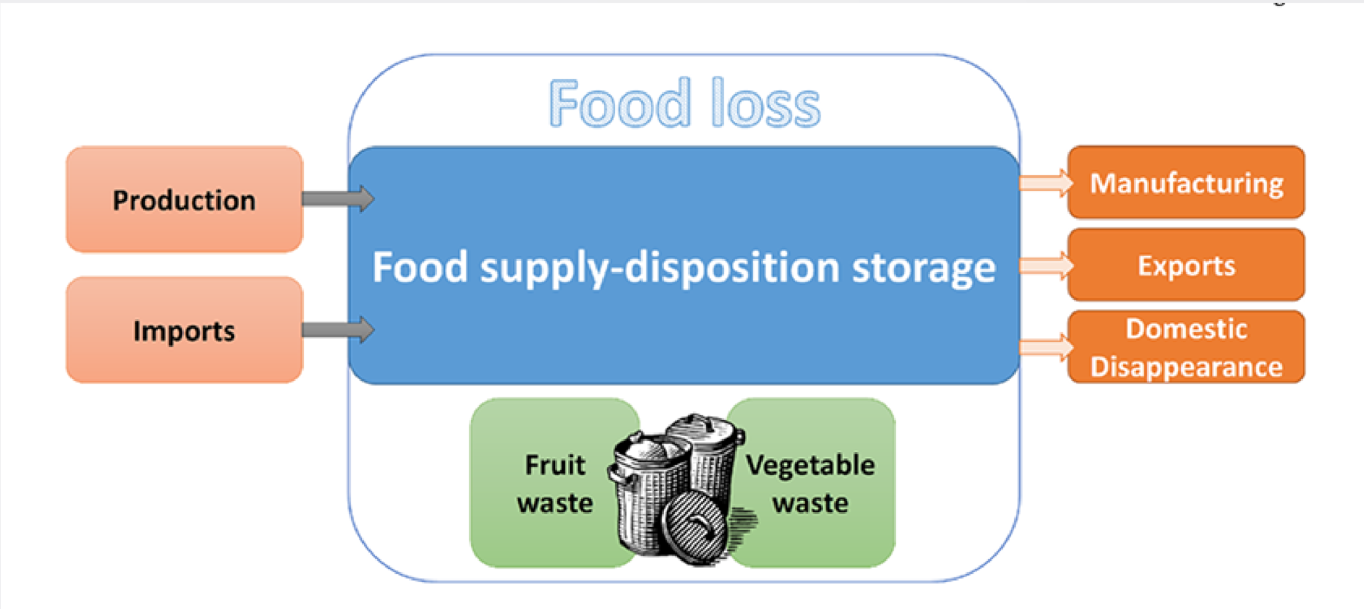
Data Collection
- Statistics Canada (SC)
- Agriculture and Agri-Food Canada (AAFC)

Two developed Food Waste Indicators
- Per Capita Generation rate (PCGR)
- Food Waste Generation Ratio (FWGR)

Model Input Parameters
- Production (P)
- Imports (I)
- Domestic disappearance (DD)
- Exports (E)
- Manufacturing (M)

Trend Analysis
- Pearson correlation
- Linear Regression

MLR models
- Dual step model
- Stepwise model



Two food waste indicators

1. Per capita generation rate (PCGR)

$$PCGR\left(\frac{kg}{cap \bullet year}\right) = \frac{Food\ waste\ generation\ at\ supply\ anddisposition\ storage\ (kg/year)}{Population\ of\ the\ corresponding\ year\ (up\ to\ July\ 1st)}$$

- **PCGR** quantifies the average food waste generated per person in a given year
- Higher PCGR indicate increased waste generation at the individual level and reflects **inefficiency in food distribution** systems

2. Food waste generation ratio (FWGR)

$$FWGR\ (\%) = \frac{Waste\ generation\ of\ a\ commodity\ at\ supply\ and\ disposition\ storage\ (tonnes/year)}{Total\ supply\ of\ that\ commodity\ (tonnes/year)}$$

- **FWGR** measures the proportion of a commodity's total supply that becomes waste (%)
- Higher values indicate greater losses relative to available supply, reflects **inefficiency in resource use** for that specific produce

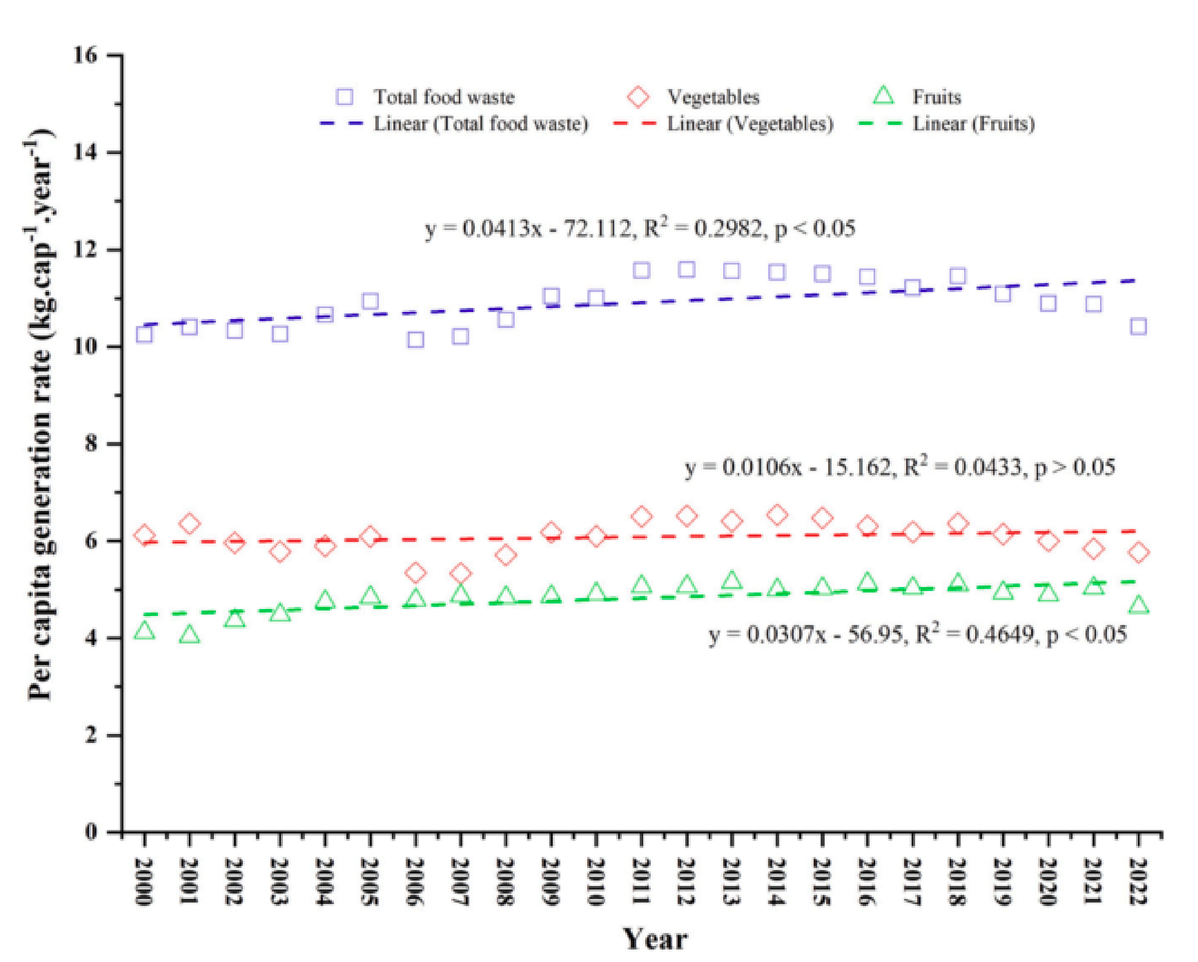
PCGR and FWGR assess supply chain efficiency and identify where waste reduction is needed

Per capita food waste generation trends

- Overall, per capita food waste shows an **increasing trend** over time (s=+0.0413)
- More vegetables were generated(avg 6.1 kg·cap⁻¹·year⁻¹) than fruits (avg 4.8 kg·cap⁻¹·year⁻¹), about 26% more

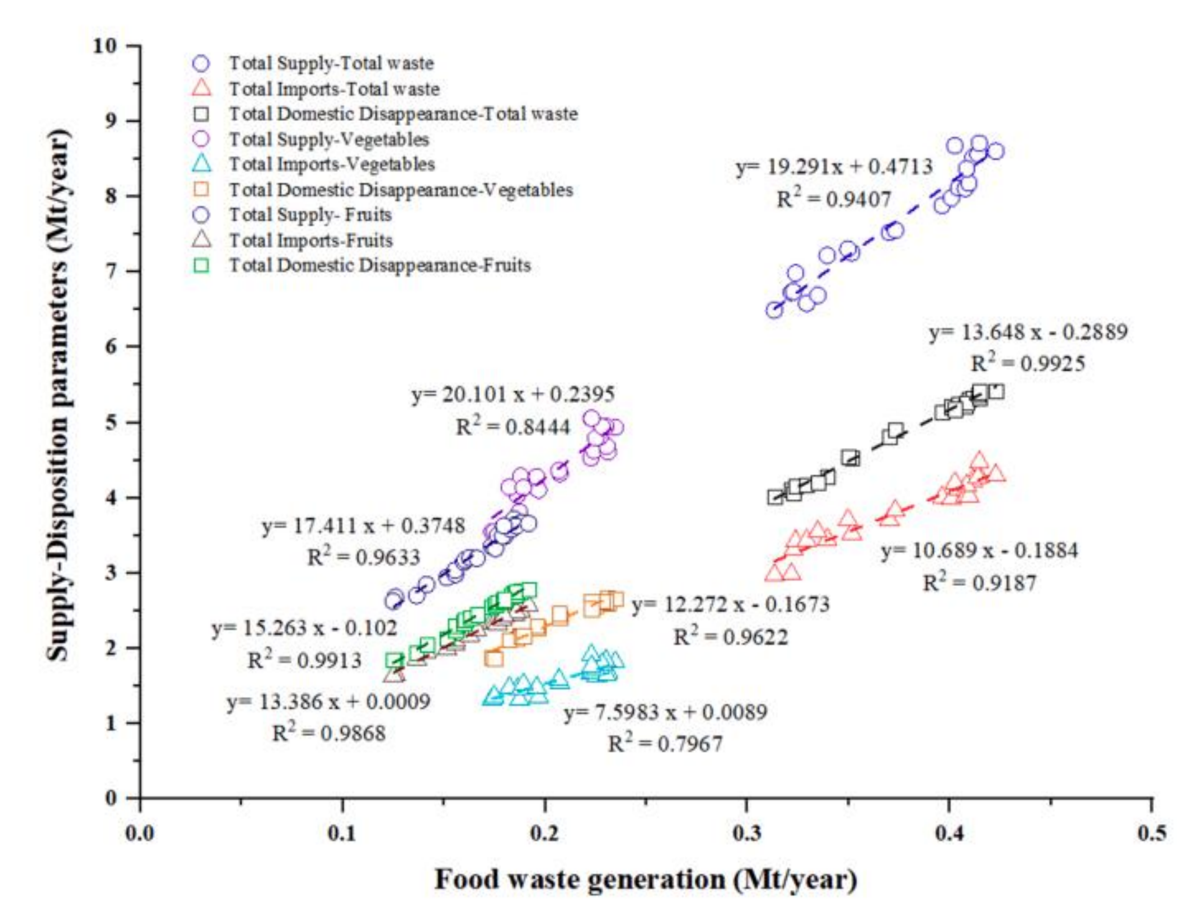
- **Higher** vegetable waste is mainly due to higher moisture content, weaker packaging, and poorer post-harvest handling compared to fruits

- However, fruit waste is **rising faster** (s= +0.03), likely driven by changing consumption patterns and import dynamics

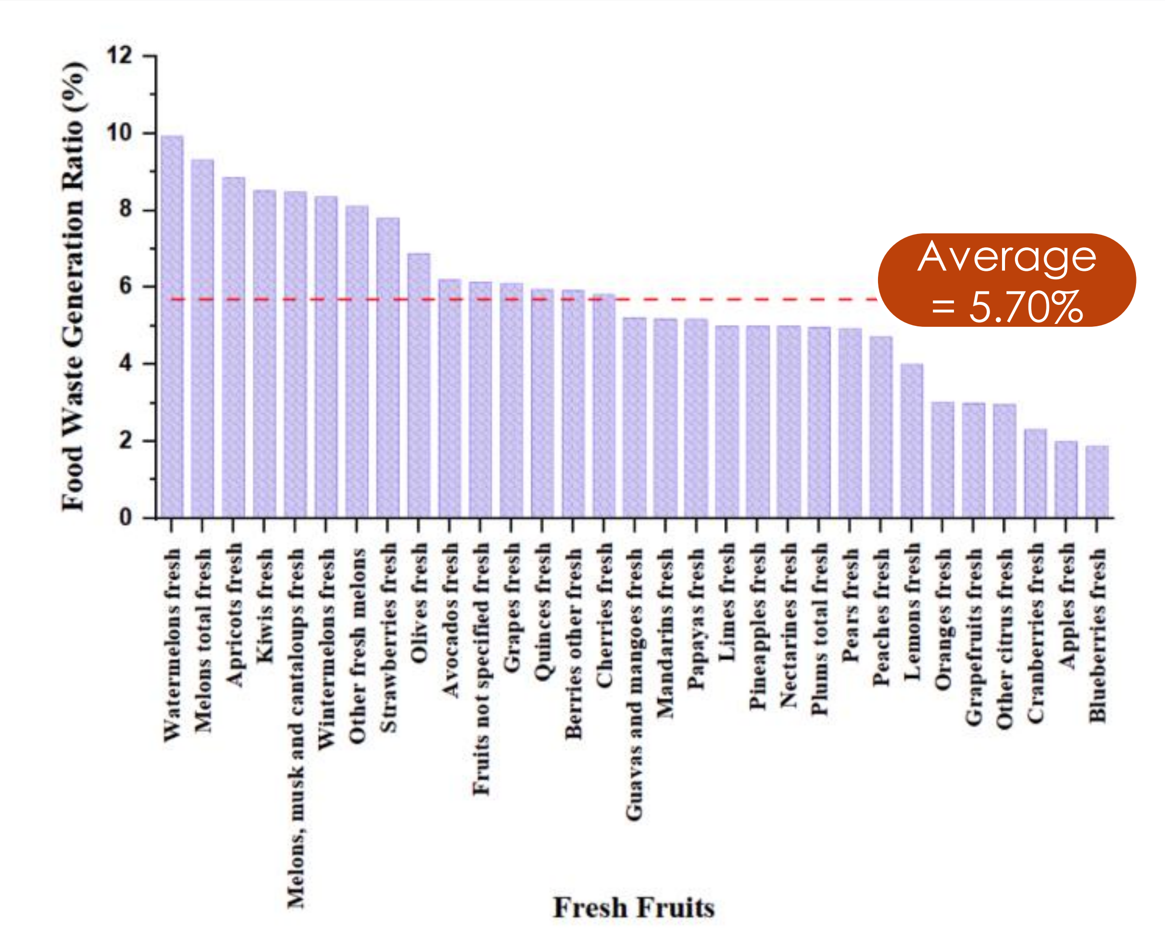


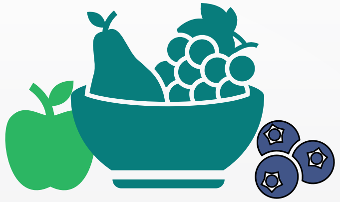
Waste generation and the supply-disposition parameters

- Food waste **strongly increases** with supply, imports, and domestic disappearance (R^2 = 0.797-0.993 and $p < 0.0001$)
- **Oversupply** and **poor demand planning** (slopes = +7.6 to +20.1) drive waste, highlighting the need to better balance supply and consumption
- **Strong links** with domestic disappearance (R^2 up to 0.99) suggest improved storage, logistics, and demand-aligned production are critical to reduce waste



Fresh Fruits

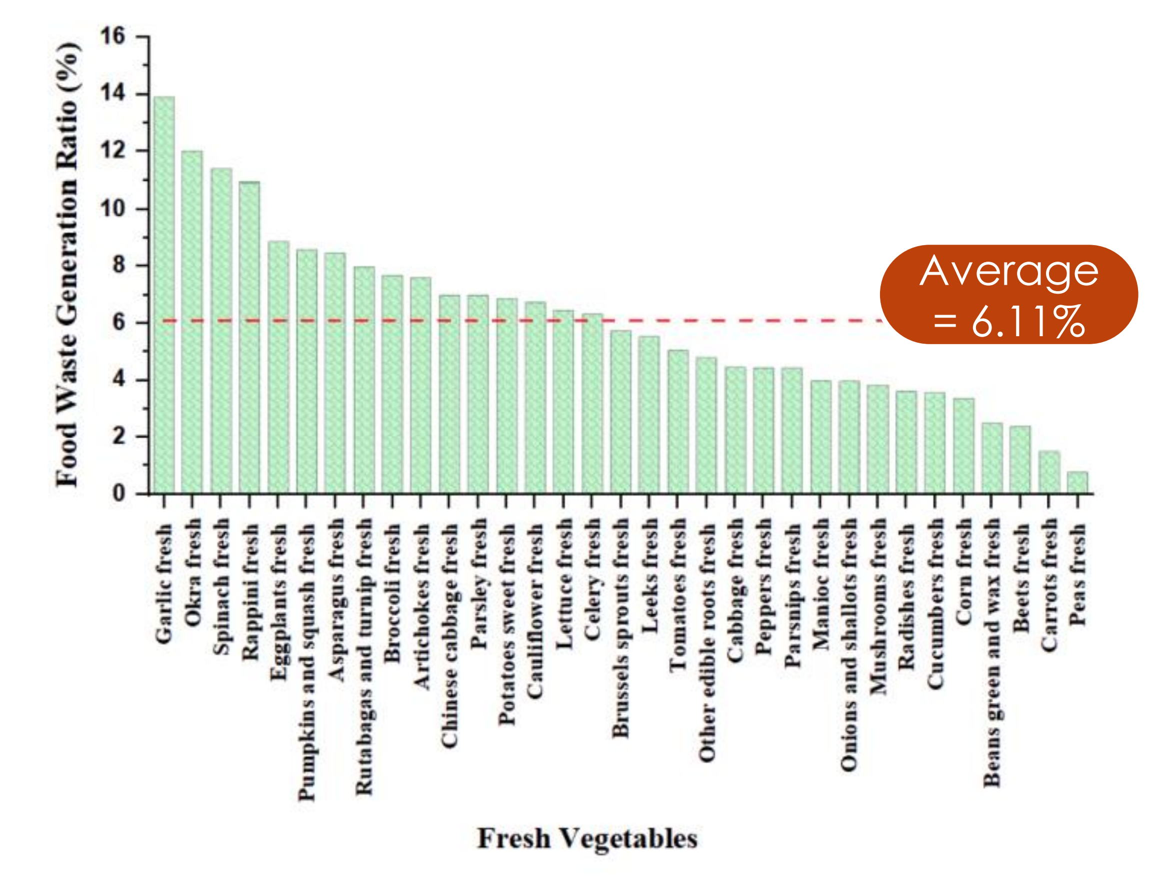




$$\textit{Food waste generation ratio (\%)} = \frac{\textit{Waste generation of a commodity at supply and disposition storage (tonnes/year)}}{\textit{Total supply of that commodity (tonnes/year)}}$$

- The highest **FWGRs** (8% to 10%) are for the melon groups (including watermelon, winter melon, musk, and cantaloupe), kiwis, and apricots
- This highest FWGR trend can be linked to their vulnerability to even minor damage

Fresh Vegetables



- The highest FWGRs (8% to 14%) are for garlic, okra, spinach, rapini, eggplants, pumpkins and squash, and asparagus.
- A substantial portion of their supply is wasted during the storage phase for these commodities

On average, *fresh vegetables* FWGR (6.11%) is higher than for *fresh fruits* (5.70%) at the supply-disposition stage

Waste Generation Models

$$Fresh\ fruit\ waste,\ \mathrm{FW}\left(\frac{kt}{yr}\right) = -0.4652 - 0.0164\boldsymbol{P} + 0.1029\boldsymbol{I} + 0.0822\boldsymbol{E}$$

$$Fresh\ vegetable\ waste,\ \mathrm{VW}\left(\frac{kt}{yr}\right) = 0.1722 + 0.2503\boldsymbol{P} + 0.2942\boldsymbol{I} - 0.2396\boldsymbol{DD} - 0.2340\boldsymbol{E} - 0.2087\boldsymbol{M}$$

- Developed models highlight the role of imports and exports in waste generation ($R^2 = 0.98$ for fruits and $R^2 = 0.92$ for vegetables)
- Differences in coefficients (e.g., imports **+0.1029** vs. **+0.2942**) indicate the need for commodity-specific management strategies
- Imports and exports are key drivers of waste (**$p < 0.0001$**)

Fresh Fruits waste at supply-disposition storage

MLR Approach	Dependent Variables	Independent Variables*	Co-efficient values	P value	R^2	F value	RMSE
Stepwise	Fruit waste generation (kt/year)	P	−0.0164	<0.0001	**0.975**	**4053.56**	**1.571**
		I	0.1029	<0.0001			
		E	0.0822	<0.0001			
		Intercept	−0.4652	<0.0001			

Fresh Vegetables waste at supply-disposition storage

MLR Approach	Dependent Variables	Independent Variables*	Co-efficient values	P value	R^2	F value	RMSE
Dual Step	Vegetable waste generation (kt/year)	P	0.2503	<0.0001	**0.924**	**746.89**	**3.318**
		I	0.2942	<0.0001			
		DD	−0.2396	<0.0001			
		E	−0.2340	<0.0001			
		M	−0.2087	<0.0001			
		Intercept	0.1722	0.549			

*P for production, I for imports, DD for domestic disappearance, E for exports, and M for manufacturing

Limitations

- **Classification uncertainty:** some items (e.g., tomatoes) may be classified as fruit or vegetables, affecting waste estimates
- **Input parameters:** factors such as shelf life, climate, and market dynamics, reducing predictive accuracy
- **Data availability:** models rely on available supply–disposition data from Statistics Canada. Trade statistics are based on customs data, and illegal smuggling of fresh produces across the international borders were assumed negligible.

Conclusions

- Food waste is strongly linked to **supply factors** (R^2 = 0.80-0.99; $p < 0.0001$), highlighting the need for better demand-supply balance and storage improvements
- On average, vegetables had 26% higher waste generation rate (209.2 kt/year vs 166.2 kt/year), while fruit waste is increasing faster (s=+3.1%)
- Higher inefficiency is observed in vegetables (FWGR 6.11% vs 5.70%), with some vegetables reaching 8-14% waste levels
- Two developed MLR models (R^2 = 0.975 and 0.924 with low RMSE) effectively predict waste and support global inventory management and targeted reduction strategies

For more information, please see:

Ecological Indicators 170 (2025) 113063

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Supply-disposition storage of fresh fruits and vegetables and food loss in the Canadian supply chain

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A R T I C L E I N F O

Keywords:
Supply-disposition storage
Food waste
Fresh food produce
Food supply chain
Food security
Responsible consumption and production

A B S T R A C T

Analyzing transportation and storage inefficiencies at the initial stages of the food supply chain is crucial for minimizing early-stage losses and enhancing food lifecycle efficiency. However, most food system studies, focused on retail and consumer stages. This study delves into the intricate dynamics of fresh fruit and vegetable waste generation at the supply-disposition storage stage, aiming to identify distinct waste generation patterns and predict food loss in Canada using regression analysis. Total food waste generation for 64 fresh fruits and vegetables exhibited a notable increase over a 22-year study period from 2000 to 2022, and fresh vegetables consistently surpassed fresh fruits in average waste generation by 25.9 %. Despite a higher per capita waste generation for fresh vegetables (1.26 kg•cap^{-1}•year^{-1}), the steeper growth rate in fruit waste emphasizes the need for nuanced strategies for each category at the supply-disposition storage. The waste generation showed a positive linear relationship with supply, imports, and domestic disappearance in the food supply chain (R^2 = 0.80 to 0.99, $p < 0.0001$), denoting a significant potential impact of supply-disposition parameters on individual waste generation. Two distinct regression models were developed to forecast fresh fruits and vegetables waste generation, and both demonstrated high predictability ($0.924 \leq R^2 \leq 0.975$) and low RMSE values ($1.571 \leq$ RMSE ≤ 3.318). Imports and exports appear crucial to minimize food loss at supply and disposition storage. The proposed analytical approach can be beneficial elsewhere to enhance fresh food supply inventory management and minimize food loss at a global level.

1. Introduction and literature review

Globally, nearly 1.18 billion tonnes of food are wasted annually, giving rise to food insecurity and environmental concerns (Ananno et al. 2021; de Gorter et al. 2021; Obuobi et al. 2022). Europe and North America produced around ten times higher per capita food waste than developing regions such as Southeast Asia and sub-Saharan Africa (Gustavsson et al. 2011; Van der Werf and Gilliland 2017). The European Union generates approximately 88 million tonnes of food waste per year (Obersteiner and Scherhaufer 2021), while an annual food loss of around 45 million tonnes is estimated in the United States (Kosseva 2009) and around 58 % of total food production in Canada gets wasted in the food supply chain yearly, equivalent to roughly 3 % of GDP (Xue et al. 2017; Withanage et al. 2021).

1.1. Fruits and vegetable supply chain and loss

According to a recent study (Sagar et al. 2018), the highest losses and waste within the food supply chain occur in fruits and vegetables, with the potential for waste in these categories to rise up to 60 %. This waste contributes to around 42 % of all food waste generation (Porat et al. 2018; Anand and Barua 2022; Ganesh et al. 2022). The degradation of perishable fruits and vegetables at the food supply chain stage depends on storage conditions and transportation operations (Ahmad and Siddiqui 2015; Balaji and Arshinder 2016). According to some studies (Caldeira et al. 2021; Magalhães et al. 2021; Obuobi et al. 2022), inappropriate and inefficient storage conditions are a major reason for the large amount of food waste generation in the supply chain.

1.2. Pre-consumer fresh produce supply chain

Food waste quantification has recently become prevalent worldwide and is a prerequisite for practical waste minimization approaches (Corrado and Sala 2018; De Laurentiis et al. 2018; Li and Roe 2024). Quantifying and analyzing food waste trends at distinct food supply stages can be highly advantageous for global food policymakers to

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https://doi.org/10.1016/j.ecolind.2024.113063
Received 4 September 2024; Received in revised form 6 December 2024; Accepted 30 December 2024
Available online 7 January 2025

- Chowdhury, R., Mim, S. J., Tasnim, A., Ng, K. T. W., & Richter, A. **(2025)**. Supply-disposition storage of fresh fruits and vegetables and food loss in the Canadian supply chain. *Ecological Indicators*, 170, 113063. https://doi.org/10.1016/j.ecolind.2024.113063

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Acknowledgements

- We would like to thank the support of the Natural Sciences and Engineering Research Council of Canada (NSERC). This research was undertaken, in part, thanks to funding from the Canada Research Chairs Program. We are also grateful for the financial support provided by the Canada Foundation for Innovation John R. Evans Leaders Fund (CFI-JELF), Innovation Saskatchewan, as well as our research and funding partners.

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