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Review Article

Regulations and Food Reformulation: Impact on Processes, Costs, and Supply Chain. A Systematic Review

Regulaciones y reformulación de alimentos: impactos en procesos, costos y cadena de suministro. Revisión sistemática

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Spanish version

Abstract

Introduction: The increase in the consumption of sugar-sweetened beverages and other products has had a direct impact on public health, promoting the adoption of regulations such as the Front-of-Pack Nutritional Warning Labeling (FOPWL). These policies aim to guide consumer decisions and encourage the industrial reformulation of products to reduce sugars, sodium, and saturated fats.
Objective: To conduct a systematic review of the available literature on the impact of labeling regulations and the reformulation of foods and beverages on industrial efficiency, costs, and supply chain dynamics.
Materials and Methods: A systematic review (SR) was conducted in indexed databases (Scopus, SciELO, etc.) covering the period between 2018 and 2025. Inclusion and exclusion criteria were applied to select studies evaluating the effects of labeling and reformulation policies on the food industry.
Results: Mandatory regulations, such as the Front-of-Pack Nutritional Warning Labeling (FOPWL), show a strong association with product reformulation, significant reductions in sugars, sodium, and fats, and improvements in industrial efficiency. No relevant negative impacts were found on employment, wages, or prices. Companies have adapted their supply chains through technological innovation, traceability, and digitalization.
Conclusions: FOPWL and reformulation are key tools to improve public health and foster innovation within the industry. However, gaps remain in the precise quantification of costs, in understanding the long-term effects on supply chains, and in comparative analyses of regulatory frameworks.

Keywords: Industrial efficiency; food reformulation; nutritional labeling; operational costs; productive sustainability.

Resumen

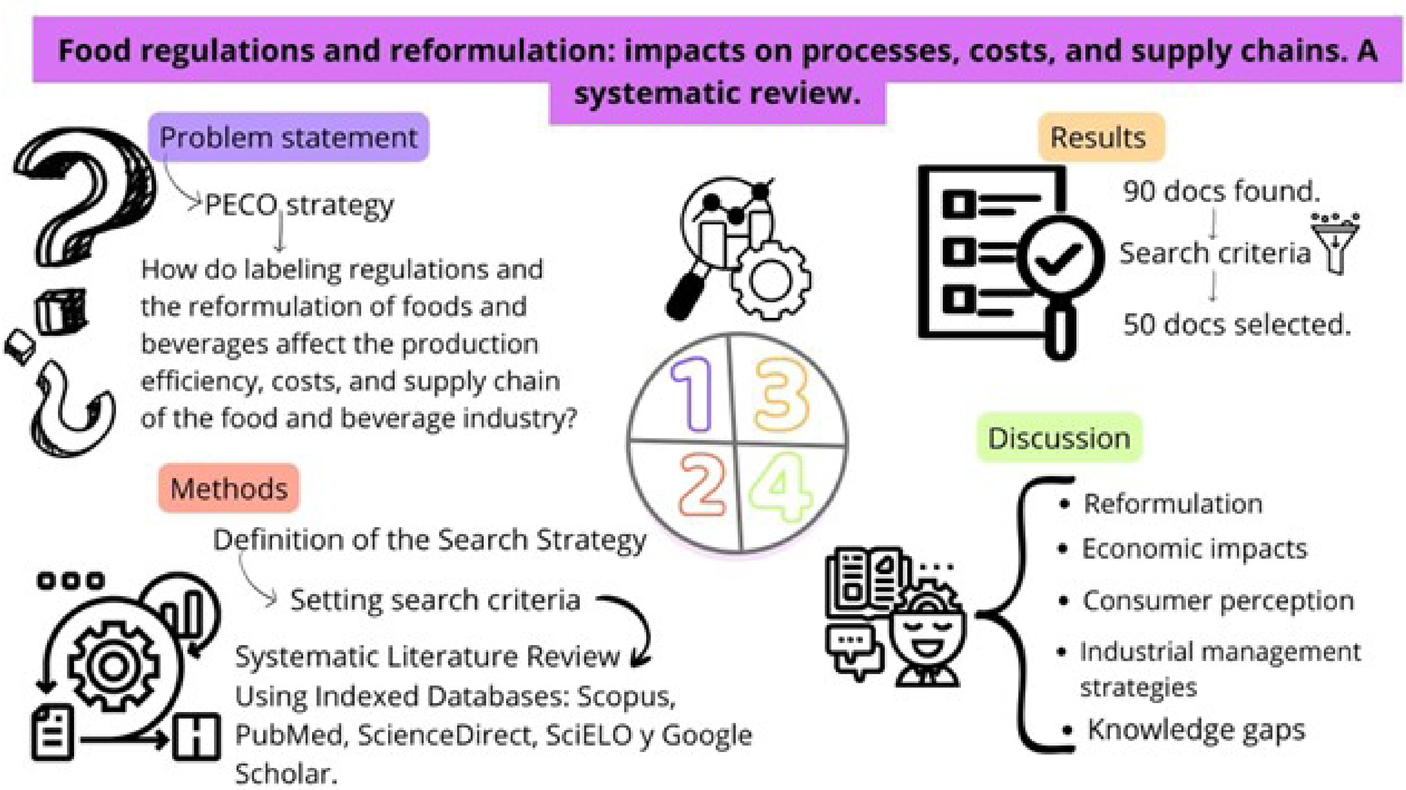
Introducción: el aumento del consumo de bebidas azucaradas y otros productos ha tenido un impacto directo en la salud pública, impulsando la adopción de regulaciones como el Etiquetado Frontal de Advertencias Nutricionales (EADA). Estas políticas buscan orientar las decisiones de los consumidores y fomentar la reformulación industrial de productos para reducir azúcares, sodio y grasas saturadas.
Objetivo: realizar una revisión sistemática de la literatura disponible sobre el impacto de las regulaciones de etiquetado y la reformulación de alimentos y bebidas en la eficiencia industrial, los costos y la dinámica de la cadena de suministro.
Materiales y métodos: se realizó una revisión sistemática (RS) en bases de datos indexadas (Scopus, SciELO, etc.) durante el período comprendido entre 2018 y 2025. Se aplicaron criterios de inclusión y exclusión a estudios seleccionados que evaluaron los efectos de las políticas de etiquetado y reformulación en la industria alimentaria.
Resultados: las regulaciones obligatorias, como el etiquetado de advertencias nutricionales en el frente del envase (EDE), muestran una fuerte asociación con la reformulación de productos, reducciones significativas de azúcares, sodio y grasas, y mejoras en la eficiencia industrial. No se encontraron impactos negativos relevantes en el empleo, los salarios ni los precios. Las empresas han adaptado sus cadenas de suministro mediante la innovación tecnológica, la trazabilidad y la digitalización.
Conclusiones: el EDE y la reformulación son herramientas clave para mejorar la salud pública y fomentar la innovación en la industria. Sin embargo, persisten lagunas en la cuantificación precisa de los costos, la comprensión de los efectos a largo plazo en las cadenas de suministro y los análisis comparativos de los marcos regulatorios.

Palabras clave: Eficiencia industrial; reformulación de alimentos; etiquetado nutricional; costes operativos; sostenibilidad productiva.

Why was it conducted?
This study was conducted to understand how front-of-pack labeling regulations and food and beverage reformulation affect industrial efficiency, operating costs, and supply chain dynamics. Despite the global expansion of these policies, the literature lacked comprehensive analysis of their economic and operational impacts. Therefore, this systematic review aimed to integrate the available evidence, identify common industrial response patterns, and provide a foundation for designing more effective and sustainable public policies.

What were the most relevant results?
The results showed that front-of-pack labeling regulations, particularly mandatory systems such as the Nutritional Warning Label (EFAN), are strongly associated with extensive product reformulation and significant reductions in sugars, sodium, and saturated fats. No major negative economic effects were observed on employment, wages, or prices. On the contrary, the evidence indicated that these policies have stimulated technological innovation, operational efficiency, and supply chain digitalization. Furthermore, nutritional warning labels proved to be more effective than voluntary systems in driving industrial change and influencing consumer purchasing decisions.

What do these results contribute?
The findings provide robust evidence of the economic and productive feasibility of front-of-pack labeling and food reformulation policies, demonstrating that public health improvement and industrial competitiveness can coexist. They also offer an empirical basis for future policy design that integrates sustainability, innovation, and efficiency criteria. Finally, the study highlights critical research gaps regarding the real costs of reformulation and the long-term effects on supply chain performance, thereby guiding new interdisciplinary research directions in industrial management and public health.



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Introduction

The growing concern about the increase in obesity and non-communicable chronic diseases has positioned sugar-sweetened beverages as one of the main targets of public health policies worldwide (1). In response to this issue, various countries have implemented regulatory frameworks that include specific taxes, front-of-pack labeling (FOPL) systems, warning labels, and modifications to mandatory nutritional labeling requirements (2). These policies aim not only to influence consumers' purchasing decisions by highlighting nutritional risks but also to promote product reformulation by the food industry (3).

The functioning of labeling regulations and beverage reformulation policies are closely interconnected. On one hand, they provide clear and accessible nutritional information that allows consumers to make more informed decisions, which can lead to a reduction in the demand for products high in sugars, sodium, or saturated and trans fats (4). On the other hand, these policies create competitive pressures that encourage producers to reformulate their products in order to avoid additional taxes, warning labels, or to maintain their market position (5).

This makes labeling regulations a powerful tool to transform both consumer behavior and industrial processes. Despite the increasing implementation of labeling regulations and product reformulation for foods and beverages worldwide, there is a lack of systematic reviews on their impacts on industrial processes, operational costs, and supply chain dynamics. Most of the existing literature has focused on evaluating the effects on product nutritional composition, consumer behavior, and public health outcomes, leaving a gap in understanding the operational, economic, and logistical implications within the supply chain for producers (6).

The problem generated by this knowledge gap is particularly relevant, as the short- and long-term economic sustainability of these policies largely depends on their ability to drive industrial changes without causing excessive disruptions to production systems or cost increases that are ultimately passed on to consumers (7). Moreover, understanding these impacts is crucial for designing more effective future policies and for anticipating industry responses to new regulations.

In this context, a systematic review is pertinent to compile, compare, and analyze the available evidence on these effects, given that current information is dispersed and fragmented across different approaches and disciplines.

Therefore, the present study aims to conduct a systematic review of the available literature on the impact of labeling regulations and the reformulation of foods and beverages on industrial processes, operational costs, and supply chain dynamics. This review seeks to synthesize the existing literature, identify common patterns in industrial responses, analyze the magnitude of documented economic impacts, and provide recommendations for future research..

Based on the above, the following key questions are proposed to guide the review:

What consumer perception factors influence industrial reformulation decisions?

What management, quality, and innovation strategies have been documented in the food and beverage industry in response to current regulations?

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How have the costs, barriers, and benefits of implementing these strategies been evaluated in production processes and within the supply chain?

Methodology

A systematic review was conducted in accordance with the PRISMA 2020 statement (8). A research question was established using the PECO strategy (Population, Exposure, Comparator, and Outcome) as follows:

Population: consumers and food and beverage industry organizations.

Exposure: foods and beverages with high sodium and sucrose content.

Comparator: reformulated or labeled products, or those with strategies for reducing critical ingredients.

Outcome: changes in consumer perception, impact on industrial management, regulatory compliance strategies, and innovation.

Based on the above, the research question is: How do labeling regulations and the reformulation of foods and beverages affect production efficiency, costs, and the supply chain within the food and beverage industry?

For better understanding and clarity, Table 1 presents the relationship between the key research questions previously formulated and the proposed general and specific research objectives.

Table 1. Relationship between formulated questions and proposed research objectives.

Associated question	Type of objective	Description
How do labeling regulations and the reformulation of foods and beverages affect production efficiency, costs, and the supply chain within the food and beverage industry?	General Objective	To conduct a systematic review of the available literature on the impact of labeling regulations and the reformulation of foods and beverages on industrial processes, operational costs, and supply chain dynamics within the industry.
What consumer perception factors influence industrial reformulation decisions?	Specific Objective 1	To identify the consumer perception factors that influence industrial reformulation decisions.
What management, quality, and innovation strategies have been documented in the food and beverage industry in response to current regulations?	Specific Objective 2	To analyze the management, quality, and innovation strategies documented in the scientific literature that the food and beverage industry has implemented in response to front-of-pack labeling and reformulation regulations.

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How have the costs, barriers, and benefits of implementing these strategies been evaluated in production processes and supply chains?	Specific Objective 3	To analyze how the scientific literature has described and documented the costs, barriers, and benefits associated with the implementation of reformulation and front-of-pack labeling strategies, as well as their implications for production processes and supply chains.

Source 1 Author's own elaboration.

Search Strategy

The search was carried out between April and June 2025 in the Scopus, PubMed, ScienceDirect, SciELO, and Google Scholar databases, considering articles published between 2018 and 2025. This range was chosen to include the most recent and relevant studies on front-of-pack labeling (FOPL) regulations and food and beverage reformulation, as most major front-of-pack labeling and reformulation policies were consolidated after 2018 (4,5,9–11).

The main search equation used —applied to article titles, abstracts, and keywords— was: ("front-of-pack labeling" OR "nutrition warning labels" OR "nutritional labeling" OR "food labeling regulations") AND ("beverage reformulation" OR "food reformulation" OR "sugar reduction" OR "sodium reduction") AND ("production process" OR manufacturing OR "industrial processes" OR "supply chain" OR logistics OR "manufacturing costs" OR "economic impact"). From Scopus, 65 potential documents were selected, and an additional 25 potential documents were gathered from the other databases.

Subsequent analysis focused on three main thematic dimensions: production processes, operational costs, and adaptations in the supply chain. These categories served as the basis for systematizing and comparing the studies, enabling the identification of common patterns, divergences, and gaps in the reviewed scientific literature.

Inclusion and exclusion criteria for the systematic review were defined as shown in Table 2 below

Table 2. Inclusion and exclusion criteria of the systematic review (SR).

Inclusion Criteria	Exclusion Criteria
Original or peer-reviewed articles (indexed journals)	News articles, editorials, letters, conference abstracts, or non–peer-reviewed literature.
Studies in Spanish, English, or Portuguese.	Studies in languages other than English, Spanish, or Portuguese.
Documents published between 2018 and 2025.	Documents published before 2018, except for key theoretical background if necessary.
Exposure: Front-of-Pack Labeling regulation and/or beverage reformulation.	Publications without full-text access or without a clear methodology.

Source 2 Author's own elaboration

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Table 3 presents the search equation applied to each database and the number of documents found:

Table 3. Search equation, databases applied, and number of documents found.

Search equation	Databases applied	Documents found
("front-of-pack labeling" OR "nutrition warning labels" OR "nutritional labeling" OR "food labeling regulations") AND ("beverage reformulation" OR "food reformulation" OR "sugar reduction" OR "sodium reduction") AND ("production process" OR manufacturing OR "industrial processes" OR "supply chain" OR logistics OR "manufacturing costs" OR "economic impact").	Scopus (largest number of documents found)	65
	Other databases: PubMed, ScienceDirect, SciELO, and Google Scholar	25

Source 3 Author's own elaboration.

Of the 90 selected documents, 2 were excluded due to duplication, 12 were discarded based on title, and 5 were excluded for lacking full-text access or a clear methodology. Another 21 were excluded based on objectives and abstracts. No additional documents were included afterward. Duplicates were identified and removed when integrating search results from different databases, ensuring that each study was considered only once in the review process. Figure 1 illustrates the identification and selection process of documents for this systematic literature review.

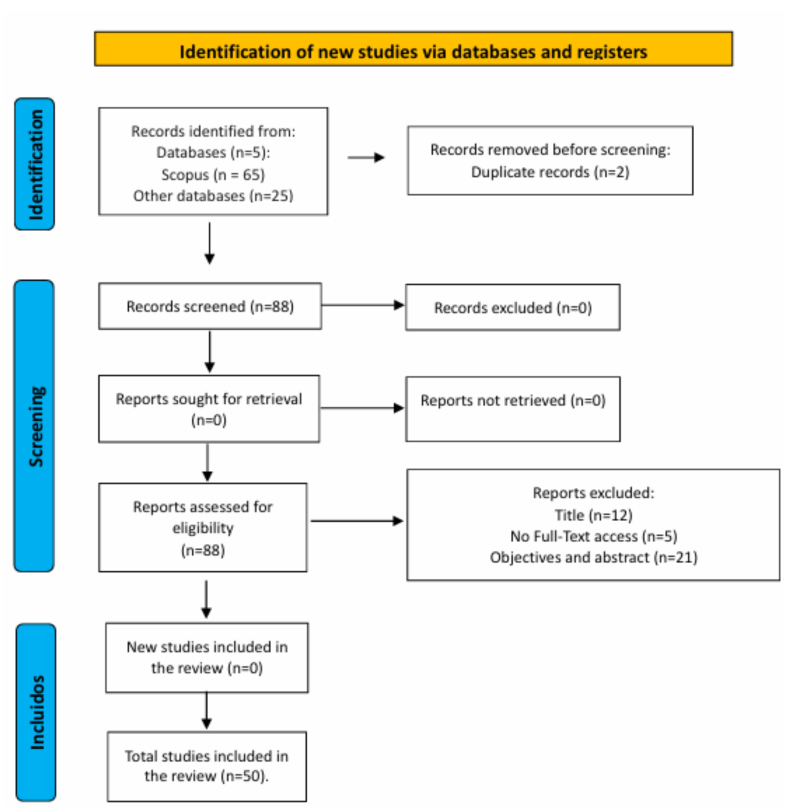

Figure 1. Process diagram for the PRISMA systematic review (8).

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Results

As shown in Figure 1, a total of 50 articles were analyzed. Meanwhile, Figure 2 presents the distribution of included publications by year (2018–2025). A progressive increase in studies is observed from 2020 onward, coinciding with the expansion of front-of-pack labeling policies in Spanish-speaking countries and other regions.

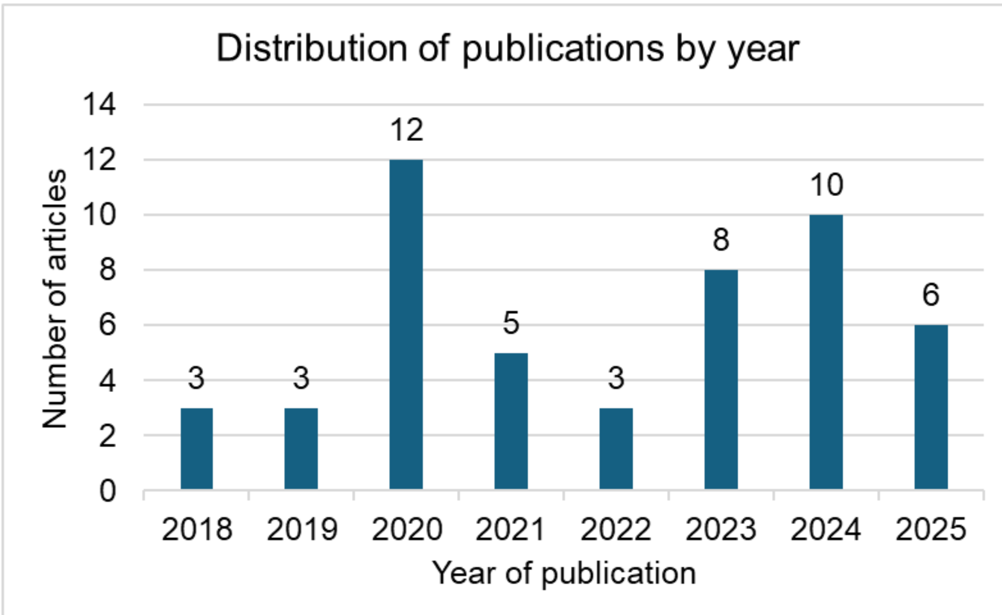

Figure 2. Distribution of publications included in the systematic review (2018–2025). Source 4 Author's own elaboration.

The systematic literature review reveals key findings on the impact of front-of-pack nutritional warning labeling and product reformulation in the food and beverage industry. With varying degrees of success, a range of regulatory approaches has been implemented internationally, and two main groups can be observed: warning or traffic-light labeling systems, as shown in Table 4, and scoring or endorsement systems, as presented in Table 5.

Table 4. Warning Labels or Traffic Light Systems — Mostly Mandatory Policies.

Country	Type of Labeling or Measure	Labeling Scope	Reference(s)
Argentina	Black-and-white octagonal warning labels. Includes precautionary legends for caffeine and sweeteners to be avoided in children.	Calories, Sugars, Saturated fats, Total fat, and Sodium.	(4,12,13)
Brazil	Black-and-white warning labels with a magnifying glass and boxes. (Implemented in October 2022).	Added sugars, Saturated fat, and/or Sodium.	(11,12)

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Canada	Black-and-white nutritional symbol (magnifying glass) highlighting the nutrient in excess. (Mandatory, implementation scheduled for January 1, 2026).	Sodium, Sugars, Saturated fat, or any combination thereof.	(9,12)
Chile	Black-and-white octagonal warning labels with the legend "High In." Implemented in progressively stricter phases (Law 20.606).	Calories, Total sugars, Saturated fats, and Sodium.	(4,5,10–12,14,15)
Colombia	Black-and-white octagonal warning labels. Includes an additional octagon when a sweetener is used.	Sugars, Saturated fat, Total fat, and Sodium.	(11,12)
Ecuador	Traffic light system using red, amber, and green colors. Bars of different sizes reflect nutrient concentrations.	Fat, Sugars, and Salt.	(11,12,14)
UEA	Traffic light labeling system.	Fat, Saturated fat, Sugars, and Salt.	(12,14)
Irán	Traffic light labeling system.	Sugars, Fat, Salt, and Trans fatty acids.	(12,14)
Israel	Red warning symbols. (Implemented since January 2020).	Sugars, Salt, and Saturated fats.	(4,11,12)
Perú	Black-and-white octagonal warning labels. Additionally, includes a warning for any amount of trans fats.	Sugars, Saturated fats, and Sodium.	(4,11,12,16)
Sri Lanka	Traffic light labeling system, specifically for beverages.	Sugars	(12,14)
Uruguay	Black-and-white octagonal warning labels. (Implemented since March 2021).	Total fat, Saturated fat, Sodium, and Sugars.	(4,11,12,14)
Venezuela	Black-and-white octagonal warning labels. (Full implementation expected by December 2024).	Sugars, Saturated fats, Trans fats, and Sodium.	(11,12)

Source 5 Author's own elaboration based on the references cited.

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Table 5. Scoring or Endorsement Systems — Mandatory and Voluntary Policies.

Country or Region	Type of Labeling or Measure	Labeling Scope	Policy Type	Reference(s)
United Kingdom	Multiple Traffic Lights (MTL). Combines intake reference values with color codes (red, amber, green).	Fat, Saturated fat, Sugars, and Salt.	Voluntary.	(11,12)
France, Belgium, Spain, Germany, Netherlands, Luxembourg, Switzerland, Portugal, Austria	Nutri-Score. Five-point color- and letter-coded scale (A–E) that assesses the overall nutritional quality of the product.	All foods.	Voluntary, government-endorsed.	(12,15–19)
Australia and New Zealand	Health Star Rating (HSR). Summary score system awarding stars (0.5 to 5) based on the nutritional profile.	Packaged products.	Voluntary, government-backed.	(12,16–18,20–22)
Sweden, Denmark, Lithuania, Norway, Iceland	Keyhole Symbol. Positive endorsement logo (green lock symbol).	Identifies healthier foods meeting sodium, sugar, fat, and whole grain/ fiber thresholds.	Voluntary, government-endorsed.	(12,14–18,21–23)
Singapore	Color-coded nutritional grading system (four levels). Also includes a red pyramid logo and slogans (“Healthier Choice Symbol”).	Mainly beverages, based on sugar and saturated fat content.	Voluntary.	(12,14)
South Korea	Multiple traffic light options, recommended mainly for certain children’s foods.	Total fat, Saturated fat, Total sugars, and Sodium.	Voluntary, government-endorsed.	(12,14)
Thailand	Monochromatic Guideline Daily Amount (GDA) labeling. Also includes a positive endorsement logo (colored symbol).	Energy, Sugars, Fat, and Sodium.	Mandatory for GDA; voluntary for endorsement logo.	(12,14)

Source 6 Author’s own elaboration based on the references cited.

The systematic review revealed that warning label or traffic light systems are the most widely adopted at the international level, representing approximately 65% of the analyzed cases, with a predominantly mandatory nature. In contrast, scoring or endorsement systems, such as Nutri-Score or Health Star Rating, account for about 35%, with a voluntary approach focused on consumer education. This is illustrated in Figure 3.

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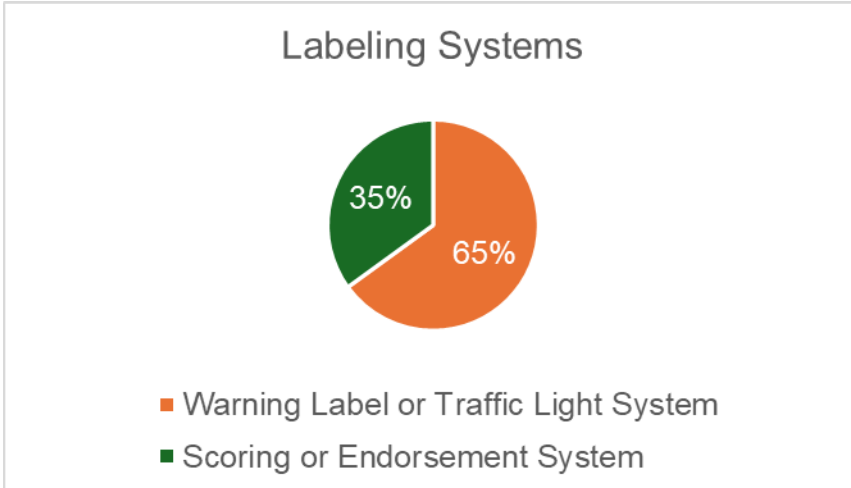

Figure 3. Nutritional labeling systems according to the type of regulatory approach. Source 7 Author's own elaboration.

Product Reformulation and Reduction of Critical Nutrients

Based on the literature, Table 6 details the most significant reformulation changes observed in specific food and beverage groups in response to regulations—primarily the mandatory Front-of-Pack Nutrition Warning Labeling (FOPNL) system—and, in some cases, voluntary or anticipatory efforts.

Table 6. Product reformulation by country and food category following the implementation of FOPL regulations.

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Country	Policy Type	Observation Period	Labeling Scope	Category	Reformulation Finding	Reference(s)
Chile	Ley 20.606	2015–2016 to 2020, year of full implementation	Sugars	Sweet spreads	Largest reduction in the proportion: from 58.0% to 13.70% (−44.30pp).	(5)
				Breakfast cereals	Reduction of 40.40pp.	(5)
				Beverages and liquid dairy	Substantial reductions of 30pp	(5)
			Sodium	Savory bakery products	Largest reduction in "High In" sodium products: from 75.7% to 36.8% (−38.90pp).	(5)
				Non-sausage meat products	Significant reduction of 38.90pp	(5)
				Fats, nuts, and snacks	Reduction of 22.00pp	(5)
			Saturated fats	Fats, nuts, and snacks	Largest reduction in "High In" saturated fats of 22.20pp.	(5)
			Global ("High In" any)	Solids	Overall proportion of "High In" products decreased from 80.5% to 66.8% (−21.70pp).	(5)
				Liquids	Overall proportion decreased from 51.9% to 26.1% (−25.80pp).	(5)
				General	Decrease from 70.8% to 52.5% (−18.30pp).	(5)

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			Sodium	Bread and other cereals	Largest reduction in "Excess Sodium" products of 63.10pp.	(7)
Mexico	NOM-051	2016 – 2021	Saturated fats	Salty snacks	Reduction in "Excess Saturated Fat" products of 26.30pp; saturated fat content reduced by 1.5 g/100g.	(7)
			Non-caloric sweeteners (NNS)	Solid dairy	Significant reduction in the use of NNS of 29.00pp	(7)
			Sugars	Beverages (All)	Substantial decrease in median sugar content, from 9.2 g/100 mL to 5.2 g/100 mL (−4 g/100 mL).	(24)
Colombia	Anticipatory or Voluntary	2016 – 2018	Calories	Beverages (All)	Decrease in median calorie content from 41.70 kcal to 25.00 kcal (−16.70 kcal).	(24)
			Non-caloric sweeteners (NNS)	Beverages (All)	Increase in the percentage of beverages containing NNS, from 33.0% to 64.0% (+31pp).	(24)
Canada	Voluntary	2017 – 2020	Sodium	General	Largest nutrient change was sodium, with 17.8% of products affected.	(25)

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United Kingdom	Sugar-Sweetened Beverage Tax – SDIL	2015 – 2019	Sugars	Sugar-sweetened beverages (Intervention)	Reduction of 33.8% in the proportion of intervention beverages above the lower tax threshold by the end of the period.	(26)
		2017	Sodium	General	Reduction of 5.1% in salt intake.	(27)
Mauritius	Mandatory. Oil regulation in the 2010s	2010s	Saturated fats, PUFAs	General	Decrease in energy from saturated fats (−3.5%) and increase in PUFAs (+5.5%).	(27)
Finland	Mandatory. Reformulation and labeling strategy, 1978–2002	1978–2002	Sodium	General	Reduction of 3 g/day in salt intake; correlation with −10 mmHg in blood pressure and 60%–80% reduction in CVD and stroke mortality.	(27)
Australia	Voluntary (HSR)	2015-2018	Sodium	General	Sodium reduction of 10.7% (2015–2018) in private-label products.	(28)
			Sugars	General	Reduction of 5.9%	(28)

Source 8 Own elaboration based on each of the references already cited.

Note: pp means percentage points; mmHg means millimeters of mercury and is a unit of measurement for blood pressure; CVD means Cardiovascular Disease; stroke refers to Cerebrovascular Accident; PUFA means polyunsaturated fatty acids.

The systematic review showed that the implementation of front-of-pack labeling (FOPL) regulations, particularly mandatory ones, is strongly associated with product reformulation by the food and beverage industry (9,27,29). The main objective of these reformulations is to modify the composition

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or processing of foods and beverages to reduce potentially harmful ingredients—such as salt, added sugars, saturated fats, and trans fats—or to increase beneficial nutrients such as fiber, proteins, or micronutrients (27).

Producers have therefore innovated and reformulated their product portfolios to include low- and no-calorie sweeteners (LNCS or NNS) as viable alternatives to sugar (12). In fact, food reformulation and fortification practices have historical precedents: the former dates back to the 1970s, while the latter began in the 1920s (27).

The Latin American experience has been pioneering in implementing labeling and reformulation policies. In Chile, Law 20.606 on food labeling and advertising establishes strict limits for critical nutrients and mandates front-of-pack warning labels. Evaluation of this policy has shown significant reductions in the proportion of products high in critical nutrients, decreasing from 70.8% to 52.5%, equivalent to an 18.3 percentage point reduction after full implementation (5). This law, applied in three progressive phases, showed a 7.0 pp decrease (from 51% to 44%) in the first years, and a total reduction of 17.8 pp (from 70.8% to 52.5%) in "high in" sugar and sodium products (9,29,30). However, some nutritional compensations were observed, such as increases in sodium levels in breakfast cereals (30).

In Mexico, the front-of-pack warning labeling system (NOM-051) has shown clear evidence of food and beverage reformulation. In particular, a significant sodium reduction was observed in baked goods and cereals, with a maximum decrease of 63.1 pp (7), as shown in Table 6. In Colombia, where reformulation measures have been anticipatory or voluntary, sugar content in beverages dropped from 9.2 g/100 mL to 5.2 g/100 mL, and caloric value decreased from 41.7 kcal to 25.0 kcal, although minimal changes were observed in nutrients such as sodium or saturated fats (24).

In North America, the United States adopted a different approach through updates to the "Nutrition Facts" label, which now requires the declaration of "added sugars" to increase transparency and encourage reformulation (31). In Canada, modeling studies suggest that implementing Front-of-Pack Nutrition Warning Labels (FOPWL) could significantly reduce sodium, total sugar, and saturated fat intake, with a 17.8% decrease in sodium content observed between 2017 and 2020 (9).

In Europe, the United Kingdom has shown notable results with the Soft Drinks Industry Levy (SDIL), implemented in 2018, leading to an estimated 2.3 g per 100 mL (38%) reduction in sugar levels in targeted beverages, directly attributed to reformulation (26). A 5.1% reduction in total salt intake was also reported (27). In Finland, reformulation and labeling strategies implemented between 1978 and 2002 reduced dietary salt intake by 3 g/day, correlating with a 10 mmHg decrease in blood pressure and a 60–80% reduction in mortality from cardiovascular diseases (CVD) and strokes (27). Denmark, on the other hand, banned trans fats (TFA) in 2004, achieving a 3.2% annual reduction in deaths from cardiovascular diseases during the following three years (27).

In Oceania, Australia shows broad adoption of voluntary front-of-pack labeling, with 81.5% of supermarket private-label products displaying some type of FOPL, although only 55.1% use the Health Star Rating (HSR) system (32). Between 2015 and 2018, reductions of 10.7% in sodium and 5.9% in sugars were recorded, attributed to the introduction of new products and reformulation of existing lines (28).

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Finally, in Africa, Mauritius implemented mandatory regulations on edible oils during the 2010s, achieving a decrease in energy from saturated fats (−3.5%) and an increase in polyunsaturated fatty acids (+5.5%), leading to a reduction in total cholesterol levels in the population (27).

Economic Impact on the Industry

The literature suggests that labeling and reformulation regulations have had real and tangible effects on the nutritional composition of beverages and foods available in the market. Reductions in sugar content, increases in the use of non-caloric sweeteners, and changes in the formulations of existing products have also been reported (24,33), as shown in Table 6. However, these changes in product composition represent only the surface of deeper transformations occurring in the production processes, costs, and supply chains of the food and beverage industry.

Producers have had to adapt their production lines, modify their raw material procurement processes, renegotiate contracts with suppliers, and, in many cases, make significant investments in research and development (R&D) to create new formulations that comply both with regulatory requirements and with consumer acceptance (33,34).

These operational adjustments have important economic implications that extend beyond the direct costs of reformulation and include effects on production efficiency, inventory management, and supply chain coordination.

Accordingly, Table 7 reflects the economic impact of regulations and reformulation on costs, particularly operational costs.

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Table 7. Operational and Reformulation Costs.

Economic Metric	Quantified Amount/ Value	Context	References
Reformulation Cost per Product	Approximately between USD 5,000 and USD 4 million per product	Estimate from the U.S. FDA Reformulation Cost Model (2014)	(27)
Additional Cost per Serving	Increase of USD 0.03–0.12 per serving	Observed in the reformulation of foods targeted at children.	(27)
Modeled Reformulation Cost (Worst Case)	£25,000 GBP per product line	Average cost used to estimate the worst-case scenario of salt reduction across 20,000 product lines in a modeling study	(35)
Total Modeled Cost (Mandatory Reformulation)	USD 1,174.5 million (10-year cumulative cost)	Worst-case cost scenario for mandatory reformulation in a salt reduction modeling study in Japan	(35)
Total Modeled Cost (Labeling)	USD 91.6 million (10-year cumulative cost)	Projected cost of implementing a labeling system (including stock and monitoring costs) in a Japanese salt reduction modeling study	(35)
Profitability from Reformulation	USD 1 million in gross profit typically equals USD 3–4 million in sales	Industry respondent's perspective: reducing a single nutrient (e.g., sugar) can generate millions in "pure profit," incentivizing reformulation.	(27)

Source 9 Author's own elaboration based on references cited in this table.

In turn, food and beverage supply chains are inherently vulnerable to disruptions due to characteristics such as seasonality and the short shelf life of products (34). Likewise, taxes on unhealthy foods can have a regressive impact, with low-income households bearing proportionally higher costs (36).

Despite the industry's initial concerns about potential negative economic effects, rigorous studies conducted in Chile found no evidence that these regulations caused significant reductions in overall employment, real wages, or gross profit margins in the food and beverage manufacturing sector (10).

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This can be seen in Table 8, which summarizes the observed outcomes in Chile.

Table 8. Sectoral Economic Impact: Employment, Wages, and Profits (Chile)

Economic Metric	Trend of Change	Quantifiable Amount	Description	Reference
Aggregate Employment	Increased	13,3%	Average increase in the number of workers in the food and beverage sector between the pre-intervention period (Jan 2013–May 2016) and the second intervention phase (Jul 2018–May 2019).	(10)
Real Wages	Increased	6,2%	Average increase in real wages in the food and beverage sector between the pre-intervention period and the second intervention phase.	(10)
Wage Trend	Slight Decrease	Monthly decrease of 0.1%	The regulation resulted in a very small and marginally significant decline in the trend of real wages and gross profit margins compared to the unaffected control group.	(10)
Cumulative Wage Impact	Slight Increase	Without the law, real wages would have been 2.4% higher	Estimated cumulative impact by the end of the 3.5-year period (May 2019), representing an economically insignificant annual increase of 0.8%.	(10)
Gross Profit Margin	Slight Decrease	Mean from 0.053 (pre-intervention) to 0.047 (second phase)	Gross profit margin (as a proportion of sales) in the food and beverage sector. Time series analyses showed no significant change in profit margins.	(10)
Number of Companies	Increased	Increased at a monthly rate of 0.3%	Trend in the number of companies in the food and beverage manufacturing sector after the first stage of regulation.	(10)

Source 10 Author's own elaboration based on the reference cited in this table.

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Additionally, reformulation costs were not consistently passed on to product prices. This challenges the common industry perception that reformulation is highly expensive and would be reflected in higher prices for consumers (10,25,37). However, the Mexican food and beverage industry has reported possible increases in production costs associated with reformulation (7). In the United Kingdom, the price of high-sugar beverages increased, but only by about one-third of the amount of the SDIL tax (13,25). This is illustrated in Table 9.

Table 9. Price Impact by Product/Market

Economic Metric	Quantifiable Amount	Description	References
Product Prices (Chile)	No significant changes in relative prices	Prices of products with warning labels, reformulated, or unlabeled remained similar to previous trends, at least during the first year and a half after the law's implementation.	(37)
Tax Impact (UK – SDIL)	Increase of £0.075 GBP per liter	Price increase for high-tax beverages (more than 8 g of sugar/100 mL), representing a 31.0% pass-through rate of the tax to consumers.	(26)
Brand Impact (UK – SDIL)	49% pass-through rate	Observed specifically for branded drinks in the highest tax tier.	(26)
Reverse Pass-Through (UK – Own Brands)	Increase of 68.6p per liter (381% pass-through rate)	Own-brand beverages in the lowest tax tier (5–8 g/100 mL) experienced a significant price increase, more than three times the amount of the tax.	(26)
Price Impact (Canada)	No significant differences in price changes	Reformulation (both reduction and increase of nutrients) was not consistently associated with price changes across most food and beverage categories in Canada (2017–2020).	(25)
Relative Prices (U.S. – GE Labeling)	13.0% price reduction	Observed in beet sugar products (labeled as GMO) in Vermont.	(37)

Source 11 Author's own elaboration based on references cited in this table.

Additionally, it is noteworthy that there is a significant scarcity in the literature regarding the impacts on production processes, operational costs, and supply chain dynamics, including R&D expenses, equipment modifications, quality control, and transition costs (13,38).

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Impact of Regulations and Reformulation on the Food Supply Chain

The food supply chain (FSC) is a complex network that integrates production, storage, distribution, and commercialization processes until products reach the final consumer (39). The review results show that nutritional regulations—especially Front-of-Pack Nutritional Warning Labeling (FOPWL) and mandatory reformulation policies—have generated significant transformations across different links of the FSC, affecting operations, technological strategies, and sustainability (27,33).

The main impacts and industrial responses can be summarized in three dimensions. First, product reformulation acts as a driver of change within the FSC, as it requires manufacturers to adjust their production lines, seek new ingredient suppliers, and modify logistical and storage processes (3,7,24,27). This adjustment has led to the adoption of differentiation strategies, introducing reformulated or healthier versions, as well as direct reformulation strategies that replace previous formulations without altering the existing portfolio (3,27). Second, operational and technological challenges have emerged from the substitution of critical ingredients. The reduction of salt, sugars, or saturated fats requires finding substitutes that maintain taste, texture, stability, and product shelf life, which has spurred investment in innovation and applied research within the supply chain (10,12,27).

Finally, global "spillover" or "contagion" effects have been identified. Multinational companies that reformulate products to comply with strict regulations—such as those in Chile or Mexico—tend to export reformulated versions to other markets, thereby extending the impact of regulatory policies internationally (10,11,24). Retailers also play a decisive role, especially through their private labels, by requiring suppliers to meet nutritional standards or prioritizing the distribution of products with improved profiles (9,28,32,33).

Sustainability and digitalization have emerged as key factors in the resilience of the FSC (34,40,41). Technologies such as Blockchain and the Internet of Things (IoT) improve traceability, quality control, and risk management (39,40). Likewise, the adoption of flexible strategies—such as supplier diversification and the use of safety inventories—helps mitigate disruptions and strengthen the capacity to respond to new regulations (34,39–41)

Consumer Perception and Behavior

Front-of-Pack Nutritional Warning Labeling (FOPWL) enables consumers to accurately, easily, and quickly identify products that exceed critical nutrient thresholds, thereby improving their understanding, perception, and purchasing decisions toward healthier options (11,14–18,20,42–44).

In contrast, labeling systems such as the Guideline Daily Amounts (GDA) are consistently ineffective, confusing, and unhelpful to the general public, even for nutrition professionals (17,42,44). Consumers—including those with higher education levels—struggle to comprehend and use the nutritional information provided by GDAs, as interpretation requires substantial time and mathematical skills (42). Table 10 presents the effects on consumers and the industry according to the type of labeling system.

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Table 10. Effectiveness of FOPL Labels on Consumers and the Industry

Type of Labeling	Effect on Consumers	Effect on the Industry	References
Warning Labels (Octagonal Seals)	Directive systems, simple and easy to understand. Greater ability to guide consumers toward healthier options and discourage purchases.	Greater extent of reformulation. Mandatory systems (Chile, Mexico) yield the greatest benefits by motivating reformulation to avoid the warning label.	(7,11,15,17,42)
Guideline Daily Amounts (GDA	Less effective. Require considerable cognitive effort (numerical calculations) that consumers typically do not perform while shopping, especially when time is limited.	No effect on reformulation. Literature suggests these labels are poorly understood and therefore unlikely to influence either industry or consumers.	(11,15,42)
Scoring Systems (Nutri-Score, HSR)	May improve the quality of supermarket purchases, though further evidence of real-world impact is needed. Promising approach. HSR is voluntary and showed limited reformulation effects in New Zealand.	Limited/Voluntary reformulation. Voluntary systems generally show more limited effects than mandatory ones. Reformulation often occurs only in products already meeting the criteria.	(11,16)

Source 12 Author’s own elaboration based on references cited in this table.

However, some studies present mixed results regarding the impact of Front-of-Pack Nutritional Warning Labeling (FOPWL) on consumer purchasing behavior, and its effectiveness may vary depending on the consumer’s familiarity with the system and the type of food category (21). Nevertheless, it is also clear that digital technologies—such as Artificial Intelligence (AI) and Big Data—serve as tools that allow the industry to collect data on consumer preferences, optimize reformulation processes, manage quality, forecast demand, and ultimately maintain market appeal and brand image (23).

Discussion

The discussion of these results is structured around the key research questions previously formulated, interpreting the different studies and connecting them to the central research question regarding the impact of regulations on production efficiency, costs, and the supply chain.

What consumer perception factors affect industrial reformulation decisions?

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Consumer perception factors are a fundamental driving force behind industrial reformulation decisions. The effectiveness of front-of-pack labeling systems, such as FOPWL, lies in their ability to simplify nutritional information and make it easily understandable at the point of purchase (11,14,17,42,44).

Consumer information processing and contrast with non-interpretive systems

Consumers tend to make food purchasing decisions quickly and impulsively (11,15,45). A front-of-pack label that is highly visible, easy to understand, and leverages automatic associations—such as colors or warning icons—is more influential in this context (11,15,45). The FOPWL system, with its simple formats, colors, and icons, facilitates rapid comprehension and easier differentiation between healthier and less healthy products (42,45).

In contrast, Guideline Daily Amount (GDA) systems, which require more deliberate and analytical cognitive processing—including numerical calculations and complex comparisons—are ineffective (11,15,42). This is particularly problematic for groups with low levels of education or limited numeracy skills (11). Consequently, the lack of understanding of GDA labels fails to generate sufficient pressure on the industry to make significant changes to its products (42).

Influence on demand and pressure to reformulate

When consumers can clearly identify products with excessive levels of critical nutrients (such as sodium, sugars, sweeteners, or trans fats) through FOPWL, their demand for healthier options increases—or, conversely, their intention to purchase less healthy products decreases (16–18,42). This shift in demand exerts direct pressure on the industry to reformulate products and avoid warning labels, thereby maintaining market appeal and brand image (27,39).

Therefore, interpretive labeling systems like FOPWL elicit a more dynamic industrial response by altering consumer perception and leading to production adjustments aimed at efficiency and regulatory compliance.

What management, quality, and innovation strategies have been documented in the food and beverage industry in response to current regulations?

Product quality management is a flexible and relevant operational strategy (42). Nevertheless, the most documented strategy in the food and beverage industry in response to front-of-pack labeling regulations is product reformulation (27). This strategy is adopted to comply with the nutritional thresholds established by public policies and, consequently, to avoid carrying warning labels (9). It is also a manifestation of quality management aimed at maintaining competitiveness and reputation (41).

While public discourse tends to focus on health improvement, companies also engage in reformulation for other reasons—such as reducing costs, increasing profits, adapting to changing consumer preferences for healthier products, entering new markets, compensating for declining sales, or complying with regulatory directives. These strategies can be observed in the different contexts summarized in Table 7, which quantifies operational and reformulation costs, showing the range of investment required according to the type of industrial intervention. More recently,

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reformulation strategies have also aligned with environmental objectives, such as reducing the carbon footprint of supply chains (46). The overall image of a company can improve and evolve from being perceived as irrelevant to being innovative and responsive through reformulation (27).

Therefore, reformulation not only represents a regulatory compliance strategy but also a pathway for technological innovation and enhanced industrial competitiveness.

Effectiveness of mandatory vs. voluntary regulations — Innovation, quality, and critiques of the approach

Although the industry has been reformulating products since the 1970s, the literature suggests that mandatory regulations are significantly more effective in driving large-scale reformulation than voluntary initiatives (22,27,29,35). Voluntary policies, such as those adopted in Australia and New Zealand, have shown limited adoption compared to mandatory labeling systems, which achieve rapid and widespread change when required by law (21,22). Voluntary reformulation allows industrial food and beverage producers to set their own agendas, monitor and evaluate themselves, and decide how many products to reformulate and to what extent—creating potential conflicts of interest (19,27).

Reformulation involves finding alternatives that maintain the taste, texture, and shelf life of the product while improving its nutritional profile. This drives innovation in ingredients and production processes (21,47). However, reformulation is also subject to criticism for promoting "nutritionism," a reductionist approach that focuses solely on altering nutrient profiles without addressing the ultra-processed nature of many foods and beverages—an aspect that may have more harmful health effects and is not necessarily mitigated by nutrient adjustment (16,27).

How have the costs, barriers, and benefits of implementing these strategies been evaluated in production processes and supply chains?

The evaluation of the costs, barriers, and benefits of implementing reformulation and front-of-pack labeling (FOPL) strategies offers a balanced perspective on their impact.

As previously mentioned, FOPL regulations — by encouraging product reformulation — demonstrate a positive, modeled effect on public health (12,35). Studies project reductions in mortality associated with cardiovascular diseases, diabetes, and cancer, as well as gains in Quality-Adjusted Life Years (QALYs) (9,12,27). For example, in Canada, it is estimated that a FOPL policy could prevent or postpone up to 8,907 diet-related noncommunicable disease (DR-NCD) deaths, mainly from cardiovascular disease (CVD) (9).

In addition, substantial healthcare savings are projected as a result of reducing the intake of critical nutrients. For instance, in Japan, the cumulative 10-year savings from reduced salt intake are estimated at USD 48.1 million (35). Moreover, reformulation leads to a food supply with improved nutritional profiles, making healthier options more accessible and abundant (48,49). In terms of consumer empowerment and rights protection, FOPL empowers consumers to make informed decisions, aligning with the right to adequate food, child protection, and informed and responsible consumption (42,50).

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Barriers and Costs

Contrary to industry claims, the Chilean experience showed that concerns over cost increases, profit reductions, or impacts on wages and employment did not materialize significantly (28). While reformulation costs do exist, they were not consistently passed on to product prices (24,30), and adaptations in the supply chain mainly involved changes in suppliers, ingredient reformulation, and logistical adjustments to ensure supply continuity (29,33,39,41).

On the other hand, voluntary reformulation initiatives face several barriers, such as an uneven playing field among companies, reluctance to reformulate best-selling products for fear of losing market share, and the possibility that firms meet reformulation goals merely by introducing new, healthier products rather than improving existing, high-consumption ones (27). Additionally, the voluntary nature of reformulation — without clear, independent oversight — may generate consumer skepticism (19,51). A further limitation is that reformulation does not necessarily address the broader issue of ultra-processed foods, often focusing narrowly on specific nutrients rather than overall product quality (16,27).

Adaptation and Sustainability of the Supply Chain under Nutritional Regulations

Findings regarding the food supply chain (FSC) confirm that labeling and reformulation regulations transcend the final product, affecting the entire structure and performance of the production network (3,7,11,24,43). Companies have had to reconfigure material flows, supplier relationships, and quality control processes, integrating nutritional management as a component of production efficiency (27).

The literature suggests that more diversified and technologically advanced supply chains are more resilient to the transition costs imposed by new regulations (41). Digital tools for traceability and real-time monitoring reduce post-harvest losses, improve transparency, and allow for the quantification of environmental impacts, as the sector accounts for over 80% of total emissions in the food and beverage industry (34,39,46).

Similarly, retailers have emerged as key actors with significant influence over the FSC by imposing reformulation criteria on suppliers or redesigning product portfolios toward healthier options (28,33). This vertical pressure capacity demonstrates that regulatory compliance and sustainability management depend not only on manufacturers but on the entire logistical and commercial network (39,46). In summary, the FSC is undergoing a transition toward more sustainable, digitalized, and flexible models, driven by regulations that, although originally designed for public health purposes, now act as catalysts for industrial innovation, operational efficiency, and environmental impact reduction throughout the value chain (27,42,45,46).

Finally, the review reveals critical knowledge gaps in current research. There remains a shortage of studies accurately documenting the costs associated with product reformulation — including investments in research and development (R&D), equipment modifications, quality control adjustments, and transition costs during the implementation of new formulations (13). Likewise, evidence on supply chain impacts remains fragmented and lacks longitudinal analyses that could clarify medium- and long-term adaptations. This includes changes in supplier relationships, sourcing patterns, inventory management, and distribution systems (38).

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Therefore, the reviewed literature demonstrates that front-of-pack labeling regulations and product reformulation have produced positive public health impacts and manageable economic effects on the industry. Although initial adaptation costs are inevitable, these tend to be offset in the medium term through innovation, operational efficiency, and strengthened industrial competitiveness. However, the absence of comparative studies across different regulatory frameworks prevents a full quantification of the real economic impact on productivity and sectoral sustainability. Future research should integrate economic, operational performance, and technological innovation indicators to guide the design of policies that maximize public health benefits while minimizing unnecessary industrial costs.

Limitations and Challenges for Future Research

This systematic review presents several limitations that should be considered when interpreting its findings. First, the analysis was based on studies published between 2018 and 2025; while this range captures the most recent evolution of FOPL and reformulation policies, it may exclude earlier studies of historical or theoretical relevance. Second, the search focused on academic databases and open-access digital directories, which limits the inclusion of gray literature, technical reports, or institutional documents that could offer complementary insights.

Furthermore, the included studies employed heterogeneous methodologies — ranging from economic analyses to qualitative policy evaluations — making it difficult to directly compare results or quantitatively estimate economic and supply chain impacts.

Regarding future research challenges, key gaps remain in the quantification of real reformulation and innovation costs, the longitudinal tracking of structural changes in supply chains and supplier relationships, and comparative analyses across regulatory frameworks to determine which generate the greatest public health benefits with the least industrial disruption. Future studies should address these issues using interdisciplinary approaches, integrating economic, technological, and sustainability analyses to strengthen the evidence base and guide the design of more balanced and effective public policies.

Conclusion

The systematic review of the literature demonstrates that front-of-pack labeling (FOPL) regulations, particularly the Nutritional Warning Labeling System (EFAN), together with product reformulation, constitute decisive tools for transforming the food and beverage industry and promoting public health. These regulations directly influence production efficiency, operating costs, and the supply chain by encouraging manufacturers to reformulate products to avoid warning labels. Far from generating negative economic effects, the evidence shows that productive transformations derived from labeling have fostered innovation, efficiency, and industrial competitiveness without significantly affecting employment or final prices, confirming the economic feasibility of such measures.

Front-of-pack labeling, through its visual clarity and interpretive simplicity, enhances consumers' ability to identify products high in critical nutrients, encouraging healthier purchasing decisions and exerting pressure on the industry to improve formulations. The main corporate response strategy

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identified is product reformulation, which responds not only to regulatory requirements but also to market interests, corporate image, and sustainability objectives. In this regard, mandatory policies have proven to be considerably more effective than voluntary ones, which tend to be slower and subject to potential conflicts of interest.

However, the review reveals significant gaps in the literature, particularly in documenting the actual costs of reformulation, technological adaptations, and supply chain impacts. The absence of longitudinal and comparative studies limits understanding of the economic and production effects of these regulations across different contexts. Therefore, future research should incorporate indicators of productivity, innovation, and industrial sustainability to guide the design of public policies that maximize health benefits while minimizing associated economic costs.

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Conflict of interest

The authors declare that they have no conflicts of interest related to this research. Ethical aspect: does not declare.

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