

Optimal wheat distribution in Mexico

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ABSTRACT

Wheat is one of the most widely consumed cereals worldwide, and its availability is pivotal to food security in Mexico. This study employed linear programming, using the simplex method, to optimize wheat distribution routes throughout the country. Two scenarios were examined: a closed economy scenario, which demonstrated that domestic production is insufficient to satisfy internal demand, and an open economy scenario, which incorporated imports to offset the deficit. The model identified the optimal routes under state-level supply and demand constraints, highlighting Sonora as the principal domestic supplier, accounting for 31% of demand, and Veracruz as a strategic entry point for imported wheat. These findings underscore that the logistical optimization of both domestic production and imports is essential to safeguarding national food security.

Keywords: simplex method, wheat in open economy, wheat in closed economy.

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INTRODUCTION

In Mexico, wheat was introduced by the Spanish in 1520 and currently constitutes, together with maize and rice, one of the most important and widely demanded crops among the population (Ministry of Agriculture and Rural Development [SADER], 2021). Its relevance lies not only in its direct consumption, but also in its strategic role within the national agri-food system and the country's food security.

Within the national territory, wheat is classified into five groups: strong (Group I), medium-strong (Group II), soft (Group III), short and tenacious (Group IV), and durum (Group V). This classification is based on gluten properties (Agri-Food and Fisheries Information Service [SIAP], 2017). Four of these groups are mainly intended for the production of bread, flour, and other soft food products, whereas durum wheat is used predominantly in pasta production.

With respect to national production, durum wheat is concentrated primarily in Sonora, followed by Sinaloa, Michoacán, Guanajuato, Baja California, Jalisco, and Chihuahua (SIAP, 2023). This type of wheat exhibits a production surplus; therefore, part of its output is even allocated to livestock feed. In contrast, bread wheat or soft wheat, which is primarily

destined for flour production, recorded an output of 1.5 million tons in that year, cultivated across 21 states, with Sonora, Guanajuato, and Michoacán standing out as the principal producers (SADER, 2022).

In the sphere of foreign trade, Mexico exports wheat mainly to countries such as Algeria, the United States, Guatemala, Türkiye, and Venezuela. However, the country remains highly dependent on imports, with the United States serving as the main supplier, followed by Canada, Russia, Ukraine, and Argentina (FAOSTAT, 2024). This trade structure clearly reveals a relative insufficiency of domestic supply to meet internal demand, particularly in the case of bread wheat.

Moreover, it is important to acknowledge external constraints that limit national production, such as diseases and pests. In the irrigated regions of Northwestern Mexico, Northern Mexico, and El Bajío, the principal diseases affecting wheat are rusts, notably leaf rust (*Puccinia triticina*) and stripe rust (*Puccinia striiformis* f. sp. *tritici*), the former being the most common and widespread in the country (Huerta *et al.*, 2011).

Added to this are international factors, such as the armed conflict between Russia and Ukraine, which has partially disrupted the global wheat supply, generating price increases and risks of shortage (Stanziani, 2023). In Mexico's case, this situation is further exacerbated by its commercial dependence on the United States to satisfy domestic demand (Espinosa, 2022), thereby exposing the country to supply vulnerabilities.

Although these elements reveal a structural problem surrounding wheat production and trade, there remains a knowledge gap regarding the efficiency of the grain's domestic distribution. In this context, logistics optimization emerges as a key factor in ensuring the timely and sufficient availability of wheat at the various points of consumption, even under scenarios of supply restriction.

Accordingly, the objective of the present research is to determine an optimal wheat distribution scheme in Mexico by identifying efficient routes that minimize resource use and make it possible to satisfy national demand. The study examines this issue under both closed- and open-economy scenarios in order to demonstrate the insufficiency of domestic supply and the strategic importance of optimal logistical allocation for strengthening the country's food security.

MATERIALS AND METHODS

In order to ensure the reproducibility of the results, this study employed a linear programming model solved using the simplex method (Ariza & Llinás, 2019). Linear programming makes it possible to optimize an objective function subject to linear constraints, under the assumptions of proportionality, additivity, divisibility, and certainty in the model parameters. The analysis was conducted under two scenarios:

- Closed economy, in which no foreign trade exists.
- Open economy, in which imports are incorporated through land and maritime customs entry points.

The model was implemented in LINGO 18 to verify the consistency of the results.

Case 1. Closed economy:

In the absence of foreign trade, the objective was to minimize the total transportation cost between producing states ($i=1, 2, \dots, m$) and consuming states ($j=1, 2, \dots, n$). The objective function is expressed as (Equation 1):

$$\text{Min } Z_{EC} = \sum_{i=1}^m \sum_{j=1}^n C_{ij} X_{ij}$$

where: Z_{EC} : linear objective function in a closed economy; C_{ij} : distance between origin i and destination j ; X_{ij} : quantity of product transported, to be determined, originating in i and destined for j .

Distances were obtained using the Point-to-Point Routes tool of the Ministry of Infrastructure, Communications and Transportation (SICT, 2024).

The 31 states and Mexico City were considered:

- If state production exceeded consumption, the state was classified as a supplier.
- If production was lower than consumption, it was classified as a demander.

Constraints: constraints refer to all variables that condition the objective function and indicate the available quantity that each supplier can provide to demanders (Alvarado, 2009). Within the system of constraints, both supply and demand restrictions were established.

Supply: to estimate total supply by state (i), total state production minus total state consumption was used, based on agricultural year-end data from the Agri-Food and Fisheries Information Service (SIAP, 2023). Therefore, (Equation 2):

$$E_i = \text{PROD}_i - \text{CON}_i \quad \forall i = 1, 2, \dots, m$$

where: E_i : wheat supply by state of origin i ; PROD_i : total wheat production at origin i ; CON_i : total wheat consumption at origin i .

In turn, total wheat consumption at origin (CON_i) was estimated using (Equation 3):

$$\text{CON}_i = \frac{\text{CNA}_{\text{wheat}}}{\text{POB}} \times \text{POB}_i$$

where: $\text{CNA}_{\text{wheat}}$: apparent national wheat consumption; POB : national population; POB_i : total population of state of origin i .

To calculate apparent national wheat consumption, total wheat imports were added to total national wheat production, and total wheat exports were subtracted (Equation 5):

$$CNA_{wheat} = PROD_{wheat} + IMP_{wheat} + EXP_{wheat}$$

where: CNA_{wheat} : apparent national wheat consumption; $PROD_{wheat}$: total wheat production; IMP_{wheat} : total wheat imports; EXP_{wheat} : total wheat exports.

Regarding imported and exported wheat quantities, data from the Statistics Division of the Food and Agriculture Organization of the United Nations (FAOSTAT, 2023) were used.

Thus, the constraint on the total quantity supplied by each origin (E_i), from each i to the m -th origin, is expressed as (Equation 5):

$$\begin{aligned} \sum_{j=1}^n X_{1j} &= E_1 \\ \sum_{j=1}^n X_{2j} &= E_2 \\ &\vdots \\ \sum_{j=1}^n X_{mj} &= E_m \end{aligned}$$

Demand: to determine total demand by destination (j), production at destination (j) was subtracted from consumption at destination (j). For these estimations, Equations 3 and 4 were adapted to the destination states j . Production data were obtained from the agricultural year-end records of the Agri-Food and Fisheries Information Service (SIAP, 2023), while national and state population data were drawn from the population census of the National Population Council (CONAPO, 2025). Finally, imported and exported wheat quantities were obtained from the Statistics Division of the Food and Agriculture Organization of the United Nations (FAOSTAT, 2023). Thus, demand was estimated as follows (Equation 6):

$$D_j = CON_j - PROD_j \quad \forall j = 1, 2, \dots, n$$

where: D_j : wheat demand by destination state j ; $PROD_j$: total wheat production at destination j ; CON_j : total wheat consumption at destination j .

The demand constraints for each destination (D_j), from each j to the n -th destination, are expressed as (Equation 7):

$$\begin{aligned} \sum_{i=1}^m X_{i1} &\leq D_1 \\ \sum_{i=1}^m X_{i2} &\leq D_2 \\ &\vdots \\ \sum_{i=1}^m X_{in} &\leq D_n \end{aligned}$$

Finally, the problem for the closed-economy case was formulated as follows (Equation 8):

$$\text{Min } Z_{EC} = C_{11}X_{11} + C_{12}X_{12} + \dots + C_{mn}X_{mn}$$

Subject to $(m+n)$ restrictions and non-negativity condition:

$$\begin{array}{cccccc} X_{11} & +X_{12} & \dots & +X_{1n} & = & E_1 \\ X_{21} & +X_{22} & \dots & +X_{2n} & = & E_2 \\ \vdots & \vdots & \ddots & \vdots & & \vdots \\ X_{m1} & +X_{m2} & \dots & +X_{mn} & = & E_m \\ \\ X_{11} & +X_{21} & \dots & +X_{m1} & \leq & D_1 \\ X_{12} & +X_{22} & \dots & +X_{m2} & \leq & D_2 \\ \vdots & \vdots & \ddots & \vdots & & \vdots \\ X_{1n} & +X_{2n} & \dots & +X_{mn} & \leq & D_n \\ \\ X_{ij} \geq 0 & \forall i=1,2,\dots,m & \wedge & \forall j=1,2,\dots,n & & \end{array}$$

Case 2. Open economy:

In this scenario, w customs entry points were incorporated (19 along the northern border, 2 along the southern border, and 17 maritime entry points), excluding airport customs due to their higher costs. The objective function was defined as follows (Equation 9):

$$\text{Min } Z_{EA} = \sum_{i=1}^m \sum_{j=1}^n C_{ij}X_{ij} + \sum_{k=1}^w \sum_{j=1}^n B_{kj}M_{kj}$$

where: Z_{EA} : linear objective function in an open economy; C_{ij} : distance between origin i and destination j ; B_{kj} : distance between origin k and destination j ; X_{ij} : quantity of product transported, to be determined, originating in i and destined for j ; M_{kj} : quantity of imported product transported, to be determined, originating in k and destined for j .

For all domestic origins (i)=1,2,..., m ; customs entry points of origin (k)=1,2,..., w ; and destination regions (j)=1,2,..., n . To estimate the distance from origin (i) and customs entry points (k) to destination (j), the Point-to-Point Routes tool of the Ministry of Communications and Transportation of Mexico (SCT, 2024) was used.

Supply: in addition to the constraints established in Equation 3, imported supply at customs entry points was incorporated (Equation 10):

$$\begin{aligned} \sum_{j=1}^n M_{1j} &\geq 0 \\ \sum_{j=1}^n M_{2j} &\geq 0 \\ &\vdots \\ \sum_{j=1}^n M_{wj} &\geq 0 \end{aligned}$$

Demand: quantity demanded by each destination (D_j), from each j to the n -th destination (Equation 11):

$$\begin{aligned} \sum_{i=1}^m X_{i1} + \sum_{k=1}^w M_{k1} &\leq D_1 \\ \sum_{i=1}^m X_{i2} + \sum_{k=1}^w M_{k2} &\leq D_2 \\ &\vdots \\ \sum_{i=1}^m X_{in} + \sum_{k=1}^w M_{kn} &\leq D_n \end{aligned}$$

In another format, the problem in an open economy was posed as the following expressions (equation 12):

$$\text{Min } Z_{EA} = C_{11}X_{11} + C_{12}X_{12} + \dots + C_{mn}X_{mn} + B_{11}M_{11} + B_{12}M_{12} + \dots + B_{wn}M_{wn}$$

Subject to $(m+n+w)$ restrictions and non-negativity condition:

$$\begin{aligned} X_{11} + X_{12} \dots + X_{1n} &= E_1 \\ X_{21} + X_{22} \dots + X_{2n} &= E_2 \\ \vdots \quad \quad \quad \ddots \quad \quad \quad \vdots &\quad \quad \quad \vdots \\ X_{m1} + X_{m2} \dots + X_{mn} &= E_m \\ \\ M_{11} + M_{12} \dots + M_{1n} &\geq 0 \\ M_{21} + M_{22} \dots + M_{2n} &\geq 0 \\ \vdots \quad \quad \quad \ddots \quad \quad \quad \vdots &\quad \quad \quad \vdots \\ M_{w1} + M_{w2} \dots + M_{wn} &\geq 0 \\ \\ X_{11} + X_{21} \dots + X_{m1} + M_{11} + M_{21} \dots + M_{w1} &\leq D_1 \\ X_{12} + X_{22} \dots + X_{m2} + M_{12} + M_{22} \dots + M_{w2} &\leq D_2 \\ \vdots \quad \quad \quad \ddots \quad \quad \quad \vdots \quad \quad \quad \ddots \quad \quad \quad \vdots &\quad \quad \quad \vdots \\ X_{1n} + X_{2n} \dots + X_{mn} + M_{1n} + M_{2n} \dots + M_{wn} &\leq D_n \\ \\ X_{ij}, M_{kj} &\geq 0 \quad \forall i = 1, 2, \dots, n \quad \wedge \quad \forall j = 1, 2, \dots, m \quad \wedge \quad \forall k = 1, 2, \dots, w \end{aligned}$$

In the case of the open economy, in addition to the 31 states and Mexico City, 38 customs offices (19 on the northern border, 2 on the southern border, and 17 maritime) were considered as a complement to the supply; to reduce costs, airport customs offices were excluded.

To ensure the robustness of the results, it was validated that all constraints were met in both scenarios.

RESULTS AND DISCUSSION

According to the information collected, by the end of 2023 Mexico had recorded a total wheat production of 3,476,026.80 tons (SIAP, 2023). In that same year, imports amounted to 4,022,527.23 tons, whereas exports totaled 126,158.51 tons (FAOSTAT, 2023). Based on these figures, apparent national wheat consumption was estimated at 7,372,395.52 tons, of which 47.15% originated from domestic production and 52.85% from foreign sources. The total population was 131,135,337 inhabitants; therefore, annual *per capita* consumption was estimated at 0.056 tons per person.

Case 1. Closed economy

In this first scenario, only three states were identified as self-sufficient in wheat production: Baja California, Sinaloa, and Sonora. The model considered the surplus of each of these states as origin supply.

The results showed that wheat allocations followed a geographically coherent pattern consistent with distance minimization. Baja California supplied Baja California Sur and Nuevo León; Sinaloa supplied exclusively Jalisco; whereas Sonora, the largest producer with more than 1.8 million tons, covered a broad range of destinations.

The optimal distribution made it possible to supply only 15 of the 29 states with demand, as shown in Table 1.

Sonora had the capacity to cover 31% of demand, Sinaloa 2%, and Baja California 0.6%, which together represented only 33.6% of national demand. The State of Mexico

Table 1. Optimal distribution of wheat in a closed economy in Mexico.

Origin (y): national supply (tons)	Destination (j): national demand (tons)	
Baja California: 36,088.52	Baja California Sur: 25,985.59 Nuevo León: 10,102.93	
Sinaloa: 117,345.46	Jalisco: 117,345.46	
Sonora: 1,821,319.50	Aguascalientes: 84,931.39	México: 163,989.81
	Chihuahua: 129,382.50	Michoacán: 7,899.22
	Coahuila: 169,984.70	Nayarit: 72,755.32
	Colima: 42,581.12	Nuevo León: 310,624.34
	Durango: 97,957.33	Querétaro: 142,413.38
	Guanajuato: 98,175.05	San Luis Potosí: 164,764.00
	Jalisco: 246,660.80	Zacatecas: 89,200.54
Total supply=1,974,753.48	Total demand=1,974,753.48	

Own source.

constituted the most critical case, recording a deficit of 809,962.94 tons, since its demand amounted to 973,952.76 tons and it received only 163,989.81 tons. An additional 14 states received no supply whatsoever, accumulating a further deficit of 3,086,405.71 tons. Overall, the national deficit under the closed-economy scenario reached 3,896,368.65 tons. This indicates that Mexico was able to satisfy only 1 out of every 3 tons demanded.

The geographical distribution of supply reveals a clear bias toward the northern region of the country, which is consistent with the location of the producing states and the cost-minimization objective function. Figure 1 illustrates this pattern.

These results are consistent with previous studies that have highlighted the high regional concentration of wheat production in Mexico, particularly in Sonora and the northwestern region of the country (Garza & Taddei, 2016; Brambila *et al.*, 2017). As these studies have warned, such concentration entails a structural vulnerability of the system under scenarios involving logistical or sanitary constraints.

Likewise, the risk associated with the Ug99 fungus, as documented in the specialized literature (Reyes, 2019), further reinforces the importance of distributing production across more regions and avoiding excessive dependence on a single producing state.

The analysis also confirms what was reported by Brambila *et al.* (2017): in order to achieve equilibrium between supply and demand, wheat yield would need to increase by at least 30%, a figure consistent with the gap observed between national demand and supply in this scenario.

In summary, the closed-economy scenario is not viable, even under optimistic assumptions of efficient distribution. Its inability to cover two-thirds of demand demonstrates that Mexico is structurally dependent on foreign trade to guarantee its food security.

Case 2. Open economy

In this scenario, the supplying states were once again Baja California, Sinaloa, and Sonora. However, due to the national deficit, imported supply from 11 optimal customs

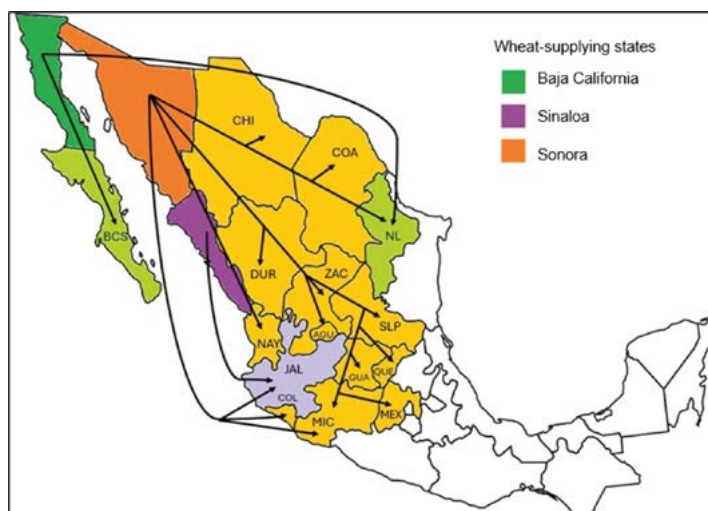


Figure 1. Wheat distribution network in Mexico under a closed-economy scenario. Source: Prepared by the authors based on the output results presented in Table 1.

entry points (1 land border crossing and 10 maritime entry points) was incorporated. The national distribution is presented in Tables 2, 3, and 4.

Here, a different pattern was observed compared with the closed-economy case: Baja California ceased supplying Nuevo León and instead supplied Coahuila. Sinaloa expanded its coverage to include Aguascalientes. Sonora increased the volume allocated to Jalisco and the State of Mexico.

Demand could not be met through domestic supply alone and was therefore complemented by imports, whose optimal pattern is shown in the corresponding tables.

The distribution presented in Table 2 contrasts with the results shown in Table 1. Baja California no longer satisfies the demand of Nuevo León, but instead supplies Coahuila; similarly, Sinaloa, in addition to covering the demand of Jalisco, also extends its supply to Aguascalientes. Nevertheless, demand is not fully satisfied by domestic supply alone; therefore, the deficit was complemented with imports. The optimal import quantities are presented in Tables 3 and 4, which highlight 11 customs entry points: one along the northern border and 10 maritime entry points. Accordingly, the open-economy scenario constitutes the optimal alternative for covering the remaining demand, which had previously been estimated at 66.4%.

The results identified only one land border customs entry point, namely Ciudad Miguel Alemán in Tamaulipas. Given that it is located along the border with the United States of America, this finding also suggests that this customs point would receive wheat from that country and potentially from Canada as well. With regard to maritime customs entry points, several of them converged on the same state, namely Veracruz, which emerged as a

Table 2. Optimal distribution of wheat in an open economy in Mexico.

Origin (i): national supply (tons)	Destination (j): national demand (tons)	
Baja California: 36,088.52	Baja California Sur: 25,985.59	
	Coahuila: 10,102.93	
Sinaloa: 117,345.46	Aguascalientes: 84,931.39	
	Jalisco: 32,414.07	
Sonora: 1,821,319.50	Chihuahua: 129,382.50	Michoacán: 7,899.22
	Coahuila: 159,881.77	Nayarit: 72,755.32
	Durango: 97,957.33	Querétaro: 142,413.38
	Guanajuato: 98,175.05	San Luis Potosí: 164,764.00
	Jalisco: 331,592.19	Zacatecas: 89,200.54
	México: 527,298.19	
Total national supply: 1,974,753.48	Total national demand: 1,974,753.48	

Prepared by the author using the output of results.

Table 3. Optimal distribution of imported wheat supply in Mexico at border customs offices.

Customs office of origin (k): imported supply (tons) Destination (j): domestic demand (tons)	Customs office of origin (k): imported supply (tons) Destination (j): domestic demand (tons)
Northern border: Ciudad Miguel Alemán, Tamaulipas: 320,727.28 Nuevo León: 320,727.28	Northern border: Ciudad Miguel Alemán, Tamaulipas: 320,727.28 Nuevo León: 320,727.28

Prepared by the authors using the output data.

strategic gateway for wheat distribution. Specifically, the optimal quantities are presented in Table 4.

Within Table 4, it was observed that the customs entry point of Tuxpan distributed the largest volume of wheat within Mexican territory, amounting to 1,553,905.54 tons, which represents 40% of the total estimated imports. Moreover, this customs point is located in the state of Veracruz; therefore, when the volumes from the Coatzacoalcos and Veracruz customs entry points are added, they total 2,344,388.73 tons, representing 61% of imported wheat supply. In other words, the state of Veracruz emerges as a fundamental pillar for the entry of imported wheat into Mexico.

Subsequently, the second state with the highest allocation for imported wheat entry was Tamaulipas, through the customs entry points of Altamira and Ciudad Miguel Alemán, which together accounted for 519,264.14 tons, representing 13% of the total imported quantity. In third place was the state of Guerrero, through the customs entry point of Acapulco, with a total of 316,308.93 tons, corresponding to 8% of imports. In the case of the remaining states, their combined share of total imports accounted for 18%.

By adding domestic supply to imported supply, national demand was fully satisfied. Specifically, total national wheat demand in Mexico was estimated at 5,871,122.15 tons, of which domestic supply, with 1,974,753.48 tons, covered 33.6%, whereas imported supply, with 3,896,368.68 tons, covered 66.4% of national demand. Thus, 2 out of every 3 tons demanded in Mexico must be supplied through imports, making foreign trade essential for meeting the needs of the Mexican wheat industry.

Table 4. Optimal distribution of imported wheat supply in Mexico at maritime customs.

Customs of origin (k): imported supply (tons)	Destination (j): national demand (tons)
Marítima: Manzanillo, Colima: 42,581.12	Colima: 42,581.12
Marítima: Acapulco, Guerrero: 316,308.93	Guerrero: 202,628.06
	Morelos: 113,680.87
Marítima: Salina Cruz, Oaxaca: 230,979.31	Oaxaca: 230,979.31
Marítima: Subteniente López, Quintana Roo: 113,541.74	Quintana Roo: 113,541.74
Marítima: Dos Bocas, Paraíso, Tabasco: 138,007.52	Tabasco: 138,007.52
Marítima: Altamira, Tamaulipas: 198,536.86	Tamaulipas: 198,536.86
Marítima: Coatzacoalcos, Veracruz: 334,287.56	Chiapas: 334,287.56
	Ciudad de México: 518,438.09
	Hidalgo: 178,938.48
	Estado de México: 446,654.53
	Puebla: 385,977.59
Marítima: Tuxpan, Veracruz: 1,553,905.54	Tlaxcala: 23,896.84
	Veracruz: 456,195.63
Marítima: Veracruz, Veracruz: 456,195.63	Veracruz: 456,195.63
	Campeche: 53,425.12
Marítima: Progreso, Yucatán: 191,297.18	Yucatán: 137,872.06
Total imported supply (maritime): 3,575,641.39	Total national demand: 3,575,641.39

Prepared by the author using the output of results.

The results for the open-economy scenario showed that only 28.94% (11 out of 38) of the customs entry points through which wheat could be imported were optimal, while the remaining customs points were not advantageous due to their distance from the producing states, which implies higher transportation costs and, consequently, renders them suboptimal.

Three relevant observations emerged from the analysis:

- Tuxpan, Veracruz, was the most important customs entry point, distributing 1,553,905.54 tons, equivalent to 40% of total imports.
- When Tuxpan, Veracruz, and Coatzacoalcos are considered together, the state of Veracruz concentrated 61% of imported wheat inflows.
- The second most relevant state was Tamaulipas, accounting for 13% of imports through Altamira and Ciudad Miguel Alemán.

Figure 2 illustrates this logistical pattern.

When domestic supply and imported supply were combined, the total demand of 5,871,122.15 tons was fully satisfied, of which domestic production contributed 33.6%, whereas imports accounted for 66.4%, equivalent to 2 out of every 3 tons consumed in Mexico.

This finding is consistent with other studies indicating that Mexico systematically ranks among the world's largest wheat importers, with a high structural dependence on foreign trade (Doporto & Michelena, 2011; Gutiérrez, 2023).

Structural and geopolitical risks (requested expansion)

The model reveals that the system depends heavily on a limited number of customs entry points. If Tuxpan or Veracruz were to experience logistical blockages, meteorological

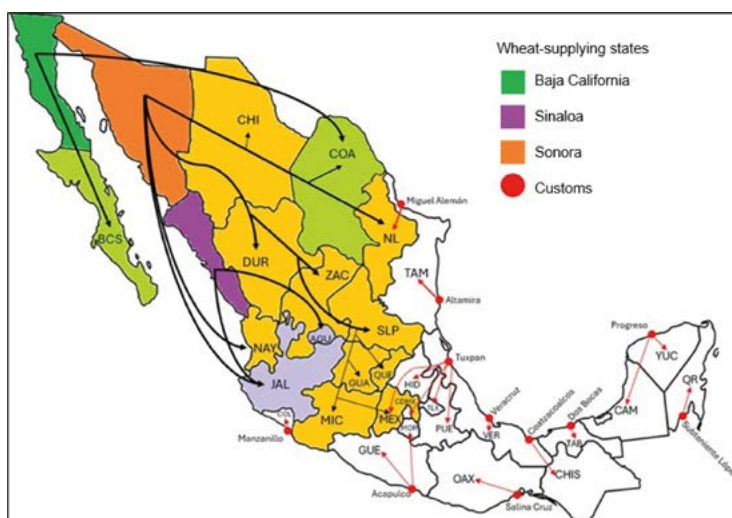


Figure 2. Wheat distribution network in Mexico under an open-economy scenario. Source: Prepared by the authors based on the model output results.

events, failures in port infrastructure, or increases in tariffs, wheat supply would be critically compromised.

The Russia-Ukraine war has demonstrated how geopolitical shocks can disrupt international wheat prices and availability, severely affecting importing countries (Gutiérrez, 2023).

In addition, the global context of inflation, economic slowdown, and trade tensions further increases the vulnerability of the Mexican system, which depends on specific ports and highly concentrated maritime routes.

Sensitivity analysis (added)

To evaluate the stability of the model, variations in domestic production can be tested:

- –10% production: the deficit would increase significantly and would require a greater use of maritime customs entry points, possibly incorporating some currently suboptimal ones.
- +10% production: imports would decline, but the general structure would remain unchanged, as Mexico would still depend on external supply.

The system is highly sensitive to agricultural yields, which is consistent with the agronomic literature.

CONCLUSIONS

The results showed that, under both the closed-economy and open-economy scenarios, Mexico does not produce sufficient wheat to satisfy its domestic demand, which makes dependence on imports unavoidable and compromises national food security. The country's total demand could only be met through a combination of 33.6% domestic supply and 66.4% imports, thereby evidencing a structural dependence on foreign trade.

The central variable of the model was the distance between origins and destinations, employed as the principal criterion in the simplex method to identify optimal routes. This approach made it possible to detect efficient distribution patterns under the logistical principle of carrying out the greatest number of activities with the smallest possible amount of resources. Under the closed-economy scenario, Sonora emerged as the predominant supplier, although total supply was able to cover the demand of only 14 states, leaving significant deficits, particularly in the State of Mexico. In contrast, under the open-economy scenario, the system exhibited greater coverage capacity due to the inflow of imports, with Veracruz consolidating its position as the most important logistical node in the country for the distribution of imported wheat.

Nevertheless, the model presents important methodological limitations. By considering distance as the sole optimization factor, it excludes real transportation costs, infrastructure availability, customs congestion, seasonal variability, and climatic or sanitary risks that could alter the optimal routes. Likewise, the model is static and does not incorporate fluctuations in productivity, international prices, or geopolitical shocks.

Based on these findings, it is suggested that decision-makers:

- Strengthen logistical infrastructure in key states such as Veracruz, Tamaulipas, and Sonora in order to reduce costs and vulnerabilities in distribution.
- Promote regionally differentiated public policies aimed at diversifying wheat production toward states with agroclimatic potential, thereby reducing concentration in the northwest.
- Advance risk-mitigation strategies, such as strategic reserves, forward contracts, and monitoring systems to respond to international crises.

As future lines of research, it would be pertinent to:

- Integrate real transportation costs, transit times, and road and port infrastructure.
- Incorporate dynamic analyses that include supply and demand projections.
- Evaluate scenarios involving productivity increases in emerging states.
- Conduct a more comprehensive sensitivity analysis considering variations in international prices, port closures, or climatic shocks.

Taken together, this study contributes to the analysis of wheat logistics in Mexico by showing, through linear programming, how the current configuration of production and the port system conditions the viability of national supply. The model demonstrates that, even under conditions of optimal distribution, wheat self-sufficiency is not attainable without reconfiguring domestic production and strengthening strategic logistical infrastructure.

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