



Honey production logistics in Mexico and its domestic market



Reyna Azucena Luna-Olea ^a

José Miguel Omaña-Silvestre ^{a*}

Juan Manuel Quintero-Ramírez ^a

Irving César Farrera-Vázquez ^b

^a Colegio de Postgraduados. Campus Montecillo. Posgrado en Socioeconomía, Estadística e Informática-Economía. Km 36.5 Carretera México-Texcoco. 56230, Montecillo, Texcoco, Estado de México, México.

^b Universidad Autónoma Chapingo. Centro de Investigaciones Económicas Sociales y Tecnológicas de la Agroindustria y la Agricultura Mundial (CIESTAAM), México.

*Corresponding author: miguelom@colpos.mx

Abstract:

Honey is a strategic resource of great importance worldwide, both from a nutritional and cultural point of view, and Mexico ranks as one of the largest global producers and exporters, with more than 58,000 t produced in 2023. Despite its leadership in production, the Mexican beekeeping sector faces serious logistical challenges, especially in internal distribution, where inefficiency in transport routes generates considerable economic losses, particularly affecting small producers. These logistical issues limit the sector's ability to meet the growing domestic demand for quality honey, affecting both the competitiveness and profitability of the sector. In this context, this study proposes an optimization model based on linear programming, the objective of which is to identify the most efficient distribution routes between producing and consuming states within Mexico. The model considers key variables, such as regional supply and demand capacities and transportation costs, in order to maximize the use of available resources. The implementation of this approach has the potential to improve the competitiveness of the beekeeping sector, increasing profit margins

for producers and facilitating access to local and national markets, which would contribute to meeting the growing demand for natural and quality honey.

Keywords: Beekeeping, Optimization, Logistics costs, Distribution, Linear programming.

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Introduction

Honey, a resource of extraordinary nutritional and cultural value, has been a mainstay of the Mexican diet and economy since pre-Hispanic times⁽¹⁾. Mexico produces more than 58 thousand tonnes per year, which ranks it as the seventh largest producer in the world⁽²⁾ and as an important exporter of this food⁽³⁾. The regions of Yucatán, Chiapas, and Jalisco stand out as the main producing areas⁽⁴⁾.

The growing demand for honey is driven by consumers who prefer natural and healthy products^(5,6), and who look for alternatives to refined sugar⁽⁷⁾. Nevertheless, the sector must comply with strict safety and traceability standards^(8,9) to guarantee the quality and competitiveness of the product in international markets.

Beekeeping is not only an economic activity within the livestock sector, but it also represents a livelihood for many rural communities and an essential element of local culture⁽¹⁰⁾. In addition to its role as a source of income for rural communities, this activity promotes sustainable agricultural practices, such as crop pollination and biodiversity conservation, providing significant environmental benefits⁽¹¹⁾.

The high costs of transporting honey constitute a significant barrier for small producers, who must deal with logistical difficulties to access larger markets⁽¹²⁾. Deficiencies in road infrastructure and logistical problems⁽¹³⁾ prolong delivery times, further aggravating the situation. In addition, the variability in logistics rates, present in other sectors⁽¹⁴⁾, affects the competitiveness and efficiency of beekeeping supply chains.

Pacheco-López *et al*⁽¹⁵⁾ and Moguel Ordoñez *et al*⁽¹⁶⁾ highlight that the lack of adequate transport technologies limits the ability of small producers to maintain the quality of honey

during transport, which has a negative impact on their competitiveness and access to more demanding markets.

Logistics optimization allows to model complex problems and to find solutions that minimize costs or maximize profits⁽¹⁷⁾. Through mathematical models and computational algorithms, it is possible to process large volumes of data and analyze various scenarios⁽¹⁸⁾. The objective is to apply strategies that optimize resources and balance supply and demand. The transport model, an approach of linear programming, is key to minimizing transport costs and meeting supply and demand constraints⁽¹⁹⁾.

This study aims to develop an optimization model for the distribution of honey in the domestic market that allows producers to improve their logistics and maximize the value of their product. The model seeks to optimize transportation from production areas to the country's regions, reducing operating costs. Since the producing areas are far from the main consumption centers, the cost of transportation has a direct impact on the final price to the consumer. By accurately identifying supply and demand zones, the model will facilitate more efficient distribution routes, reducing costs and improving production allocation at the national level.

Material and methods

In the complex environment of agrifood markets, optimizing the transport of products is key to ensuring efficient supply. This study focuses on a linear programming model designed to improve honey distribution in an open market. By considering both domestic production and consumption, the model excludes quantities destined for industry and shrinkage, thus providing a clear focus on supply.

The model is formulated by precisely defining the decision variables, which include the target function and constraints linked to supply and demand. The target function is based on the transportation costs between each origin and destination, allowing the most profitable routes for distribution to be identified.

Supply constraints represent the production capacities of each origin, whereas demand constraints respond to the specific needs of destinations. This approach ensures efficient allocation of resources, ensuring that honey reaches consumers at the right time and place.

The information used in this analysis comes from the Agrifood and Fisheries Information Service (SIAP, for its acronym in Spanish), which provides data on honey production at the

state level and by cycle. In addition, they were complemented with statistics from the National Institute of Statistics, Geography, and Informatics (INEGI, for its acronym in Spanish).

Once the origins, available quantities, and destinations of the honey demanded have been identified, the model is formulated. According to this model, variables are defined as follows: with m sources and n destinations. The quantity of supply at origin i is denoted as E_i , whereas demand at destination j is expressed as D_j . The unit transportation cost between origin i and destination j is C_{ij} , and finally, X_{ij} represents the quantity transported from origin i to destination j .

When determining the supply and demand quantities of each state of the Mexican Republic, the expression X_{mn} corresponds to each of the constraints, whereas the transportation costs between origins and destinations are represented by C_{ij} . In the design of the model, the target function is represented using Equation 1:

$$Y = \sum_i^m \sum_j^n C_{ij} X_{ij} \text{ (Equation 1)}$$

Where:

$$X_{ij} \geq 0;$$

$i = 1, 2, \dots, m$ (producing regions);

$j = 1, 2, \dots, n$ (consumer regions).

The target function is expressed as Equation 2:

$$\text{Min } Y = C_{11}X_{11} + C_{12}X_{12} + \dots + C_{mn}X_{mn} \text{ (Equation 2)}$$

Where:

Y = value of the target function;

C_{ij} = unit cost of transport from the producing center i to the consuming center j ;

X_{ij} = number of units destined from the producing center i to the consuming center j ;

X_{11} = it represents the quantity transported from source 1 to destination 1;

X_{12} = it represents the quantity transported from source 1 to destination 2.

Continuing in this manner until X_{mn} , which is the quantity transported from origin m to destination n .

With these definitions, the following constraints are formulated that condition the target function.

Supply restrictions:

$$\begin{aligned}
 X_{11}+X_{12}+\dots\dots\dots+X_{1n} &\leq E_1 \\
 X_{21}+X_{22}+\dots\dots\dots+X_{2n} &\leq E_2 \\
 \dots\dots & \\
 \dots\dots & \\
 X_{m1}+X_{m2}+\dots\dots\dots+X_{mn} &\leq E_m
 \end{aligned}$$

These restrictions indicate that the production of each center must not exceed demand, sending only the quantity requested by the consuming centers.

Demand restrictions:

$$\begin{aligned}
 X_{11}+X_{21}+\dots\dots\dots+X_{m1} &= D_1 \\
 X_{12}+X_{22}+\dots\dots\dots+X_{m2} &= D_2 \\
 \dots\dots & \\
 \dots\dots & \\
 X_{1n}+X_{2n}+\dots\dots\dots+X_{mn} &= D_n
 \end{aligned}$$

These restrictions ensure that the quantity shipped from the different production centers exactly matches the demand of each consuming center. The resulting system of equations is a set of $m+n$ equations with $m \times n$ unknowns.

In supply constraints, X_{ij} represents the quantity transported from origin i to destination j , whereas E_i is the supply at origin i , which must be equal to or greater than the demand of the consuming centers.

In demand constraints, X_{ij} represents the quantity that destination j will receive from origin i , and D_j is the demand at consuming center j . This model reflects a situation in which total supply exceeds demand (Equation 3). In a closed economy, the difference between supply and demand is processed or industrialized, since the open market is not accessed.

$$Y = \sum_{i=1}^m E_i > \sum_{j=1}^n D_j \text{ (Equation 3)}$$

Data

The analysis of national honey production in 2020 included the 31 states and Mexico City. To calculate the surplus or deficit in the production of this product, only the statistical data provided by the SIAP⁽⁴⁾ were used, which made it possible to obtain a detailed assessment of the productive situation in the country.

On the other hand, to understand the population dynamics in Mexico, data from the 2020 Population and Housing Census, provided by INEGI⁽²⁰⁾, were used. This information allowed to contextualize the distribution and characteristics of the population in the country, providing a solid basis for the analysis and consumption of honey.

Due to the few more recent official data at the time of evaluation, it was decided to use INEGI's 2020 Population and Housing Census, along with SIAP data from 2020, instead of INEGI's projections. This decision was made because the Population and Housing Census, being an exhaustive and direct count, offers more accurate and reliable data than projections, which are based on estimates and assumptions. This ensured the consistency and reliability of the analysis on honey production and consumption, without compromising the integrity of the study.

The Apparent National Consumption (ANC) was calculated by adding the national production of honey⁽⁴⁾ and imports and subtracting exports⁽³⁾, which allowed to obtain an estimate of the total consumption of honey in the country. To obtain per capita consumption, this ANC was divided by the total population of Mexico, providing a measure of average honey consumption per person. Finally, to estimate state consumption, per capita consumption was multiplied by the number of inhabitants of each state⁽²¹⁾, which allowed to obtain more precise data on honey consumption in each state, reflecting regional differences in the demand for this product.

To calculate the cost of road transport of trucks with a capacity of 25 t, the Road Transport Price Index⁽²²⁾ was used, which, in 2012, recorded a cost of 1,301 euros (€) per kilometer loaded. This value was converted to Mexican pesos (\$MXN) by using the corresponding exchange rate. Subsequently, an update factor was applied to adjust the cost to the year 2020, resulting in a value of \$30.46 MXM per kilometer.

The total cost of transportation was calculated by multiplying this value by the distance between the supplying state and the demanding state. In addition, the costs of the tolls were considered, which, although they correspond to the current year, were updated to their nominal value of 2020⁽²³⁾. Finally, the total costs of transportation and tolls were divided by the 25 t of cargo, which made it possible to calculate the cost per tonne of honey transported.

From the costs per tonne of honey transported, a cost matrix was constructed that includes both the supplying states and the demanding states, detailing the cost of transportation from each supplier to each demander. With this matrix, the target function was formulated and the corresponding restrictions were established, which considered the volumes of honey available to supply and demand in each state.

A cost minimization model was developed using the Lindo (Linear, Interactive, and Discrete Optimizer) software, V. 6.1. The results obtained were used to generate a distribution matrix that indicates the amount of honey that will be distributed according to the supplying and demanding state and that optimizes transportation costs.

Results and discussion

In 2020, Mexico produced a total of 54,165.27 t of honey, significantly exceeding both the amount destined for the industry (7,020 t) and the amount exported (22,617.56 t). This generated a surplus of 24,527.71 t, which reflects a production considerably higher than domestic demand. Thanks to this surplus, Mexico consolidated itself as one of the largest producers and exporters of honey worldwide, taking advantage of its surplus to supply international markets⁽³⁾.

As for consumption, the average per capita in Mexico was 194.6 g, based on a population of 126,014,024 inhabitants. Despite the high production, individual consumption was relatively low compared to other countries, such as Greece, Germany, Switzerland, and the United States, where it exceeds one kilogram per inhabitant⁽²⁴⁾.

Table 1 shows data on production, consumption, supply, and demand of honey from various states of Mexico. These are divided into two main groups: supplying and demanding states. Supplying states are those whose production exceeds their internal consumption, which allows them to generate additional supply to provide other states. On the other hand, the demanding states are those whose production does not completely cover their consumption, which makes them demand honey from other states to satisfy their consumption needs.

Table 1: Honey supplying and demanding states in Mexico 2020

State	Production (t)	State consumption (t)	State supply (t)	State demand (t)	Group
Jalisco	6,059.15	1,624.91	3,648.96	0.00	Supplier
Yucatán	5,528.61	451.75	4,360.34	0.00	Supplier
Chiapas	5,434.49	1,079.07	3,651.10	0.00	Supplier
Campeche	5,374.51	180.70	4,497.26	0.00	Supplier
Veracruz	4,645.22	1,569.32	2,473.86	0.00	Supplier
Oaxaca	4,592.29	804.29	3,192.82	0.00	Supplier
Puebla	2,449.60	1,281.39	850.74	0.00	Supplier
Quintana Roo	2,132.78	361.64	1,494.72	0.00	Supplier
Michoacán	2,041.85	924.33	852.89	0.00	Supplier
Guerrero	1,963.35	689.17	1,019.72	0.00	Supplier
Morelos	1,954.24	383.74	1,317.22	0.00	Supplier
Zacatecas	1,881.38	315.74	1,321.81	0.00	Supplier
Hidalgo	1,398.97	600.05	617.61	0.00	Supplier
San Luis Potosí	1,145.46	549.33	447.67	0.00	Supplier
Aguascalientes	517.94	277.48	173.33	0.00	Supplier
Colima	494.34	142.36	287.91	0.00	Supplier
Durango	471.54	356.71	53.71	0.00	Supplier
Nayarit	460.27	240.47	160.14	0.00	Supplier
Tlaxcala	454.02	261.40	133.78	0.00	Supplier
B. C. S.	201.66	155.41	20.11	0.00	Supplier
State of Mexico	876.05	3,307.45	0.00	2,544.94	Demander
Tamaulipas	708.88	686.65	0.00	69.64	Demander
Guanajuato	654.08	1,200.35	0.00	631.04	Demander
Chihuahua	637.24	728.33	0.00	173.68	Demander
Sonora	565.58	573.19	0.00	80.91	Demander
Tabasco	405.02	467.65	0.00	115.12	Demander
B. C.	297.93	733.61	0.00	474.29	Demander
Nuevo León	257.72	1,125.90	0.00	901.58	Demander
Coahuila	222.33	612.50	0.00	418.98	Demander
Sinaloa	179.35	589.17	0.00	433.07	Demander
Mexico City	96.10	1,792.65	0.00	1,709.00	Demander
Querétaro	63.36	461.00	0.00	405.86	Demander

Source: Prepared by the authors with data from SIAP, 2020.

The surplus allows states such as Jalisco, Yucatán, and Chiapas to supply honey to other regions. In contrast, consuming states face a deficit, since their total consumption amounts to 12,278.45 t, exceeding their domestic production capacity. The demand from these states

reaches 7,958.11 t, which reflects a high dependence on the supply of honey from other states, especially in places such as Mexico City, Nuevo León, and the State of Mexico, which must buy honey to meet their needs.

Although this study is based on data corresponding to the year 2020, which is considered a period with consolidated and methodologically comparable information, it is pertinent to point out that, in the following years, emerging trends of relevance for the analysis of the beekeeping sector have been identified. Preliminary reports issued by SIAP report a slight contraction in national honey production levels in 2021 and 2022⁽⁴⁾. This decrease has been attributed to the concurrence of adverse climatic factors, particularly prolonged droughts in strategic production areas, as well as to health problems that have compromised the health of the hives.

If these trends continue, a possible reduction in the national honey surplus is anticipated, which would generate additional pressure on domestic logistics systems. This scenario reinforces the need to strengthen and optimize distribution networks, with the aim of maximizing operational efficiency and the sustainability of the production and commercial system.

Table 2 presents the transportation costs, expressed in pesos per tonne, between 20 states of origin (suppliers) and the 12 states of destination (demanders) in Mexico. These costs are directly correlated with the distances traveled and the infrastructure characteristics of the routes, which implies that the observed variations reflect both the routes traveled and the specific conditions of each transport route.

Table 2: Transportation costs per tonne transported from origin to destination (MXM\$/t)

<i>i/j</i>	BC	Chih	MxC	Coa	Mex	Gto	NL	Qro	Sin	Son	Tab	Tam
Ags	2,925	1,236	682	601	669	243	858	395	1,225	2,068	1,657	646
BCS	2,017	3,545	5,361	4,511	5,253	5,006	4,596	5,108	3,754	2,877	6,336	4,979
Cam	4,799	3,302	1,484	2,529	1,572	1,948	2,595	1,746	3,099	3,943	484	2,005
Chia	4,432	2,935	1,117	2,162	1,205	1,582	2,228	1,380	2,733	3,576	313	1,638
Col	2,853	1,798	977	1,258	869	622	1,319	724	1,153	1,997	1,952	1,107
Dur	2,340	923	1,136	708	1,085	773	793	858	641	1,484	2,111	1,011
Gro	3,652	2,266	360	1,418	383	837	1,479	636	1,952	2,796	1,237	1,267
Hid	3,349	1,852	126	1,079	244	499	1,140	297	1,650	2,493	1,009	928
Jal	2,615	1,551	723	1,012	622	375	1,078	469	916	1,759	1,706	860
Mic	2,991	1,670	410	964	302	241	1,025	268	1,291	2,134	1,385	807
Mor	3,388	1,946	116	1,173	141	593	1,234	391	1,688	2,531	1,011	1,022
Nay	2,347	1,578	991	1,364	883	636	1,333	738	648	1,491	1,966	1,121
Oax	3,940	2,442	625	1,670	713	1,089	1,736	887	2,240	3,083	1,062	1,518
Pue	3,497	2,000	182	1,227	270	646	1,288	445	1,798	2,641	825	949
QRoo	5,020	3,523	1,705	2,750	1,793	2,170	2,811	1,968	3,321	4,164	706	2,226
SLP	2,840	1,315	527	553	475	230	614	249	1,379	2,222	1,502	402
Tlx	3,480	1,983	175	1,210	263	629	1,271	427	1,780	2,623	863	881
Ver	3,749	2,232	415	1,460	522	879	1,540	677	2,050	2,893	720	879
Yuc	4,992	3,494	1,677	2,722	1,765	2,141	2,788	1,939	3,292	4,135	677	2,197
Zac	2,715	1,080	837	446	824	399	531	550	1,015	1,859	1,812	636

MXM\$/t: Mexican pesos per tonne; *i*: Origin; *j*: Destination; BC: Baja California; Chih: Chihuahua; MxC: Mexico City; Coa: Coahuila; Mex: State of Mexico; Gto: Guanajuato; NL: Nuevo León; Qro: Querétaro; Sin: Sinaloa; Son: Sonora; Tab: Tabasco; Tam: Tamaulipas; Ags: Aguascalientes; BCS: Baja California Sur; Cam: Campeche; Chia: Chiapas; Col: Colima; Dur: Durango; Gro: Guerrero; Hid: Hidalgo; Jal: Jalisco; Mic: Michoacán; Mor: Morelos; Nay: Nayarit; Oax: Oaxaca; Pue: Puebla; QRoo: Quintana Roo; SLP: San Luis Potosí; Tlx: Tlaxcala; Ver: Veracruz; Yuc: Yucatán; Zac: Zacatecas.

In general, transportation costs are higher on longer-distance routes or in areas with less developed infrastructure. Conversely, shorter routes or those connecting states with better infrastructure tend to be cheaper. This indicates that, in addition to distance, the quality of road infrastructure significantly impacts transportation costs.

It is also observed that the northern and southern regions of the country have high costs on their routes to the center and southeast, which suggests that the infrastructures in these peripheral areas are less efficient. On the other hand, routes that connect the central and Bajío states with nearby areas have lower costs, reflecting better connectivity and efficiency.

According to the results obtained using the LINDO software, version 6.1, the optimal solution establishes the quantities of honey that must be distributed from each origin (*i*) to each destination (*j*), with the aim of minimizing transport costs. This distribution is calculated

under the conditions of a closed market, as presented in Table 3, which guarantees an efficient allocation of honey in terms of logistics and costs.

Table 3: Optimal closed-model distribution

<i>i / j</i>	BC	Chih	MxC	Coa	Mex	Gto	NL	Qro	Sin	Son	Tab	Tam
Ags	0.0	0.0	0.0	0.0	0.0	173.3	0.0	0.0	0.0	0.0	0.0	0.0
BCS	20.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cam	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	115.1	0.0
Col	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dur	0.0	53.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gro	0.0	0.0	0.0	0.0	1,019.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hid	0.0	0.0	617.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jal	454.2	0.0	0.0	0.0	0.0	66.2	0.0	0.0	353.8	0.0	0.0	0.0
Mic	0.0	0.0	0.0	0.0	314.9	391.5	0.0	146.6	0.0	0.0	0.0	0.0
Mor	0.0	0.0	106.9	0.0	1,210.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nay	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	79.2	80.9	0.0	0.0
Oax	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pue	0.0	0.0	850.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
QRoo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SLP	0.0	0.0	0.0	0.0	0.0	0.0	118.7	259.3	0.0	0.0	0.0	69.6
Tlx	0.0	0.0	133.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ver	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yuc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zac	0.0	120.0	0.0	419.0	0.0	0.0	782.9	0.0	0.0	0.0	0.0	0.0

i: Origin; *j*: Destination; BC: Baja California; Chih: Chihuahua; MxC: Mexico City; Coa: Coahuila; Mex: State of Mexico; Gto: Guanajuato; NL: Nuevo León; Qro: Querétaro; Sin: Sinaloa; Son: Sonora; Tab: Tabasco; Tam: Tamaulipas; Ags: Aguascalientes; BCS: Baja California Sur; Cam: Campeche; Chia: Chiapas; Col: Colima; Dur: Durango; Gro: Guerrero; Hid: Hidalgo; Jal: Jalisco; Mic: Michoacán; Mor: Morelos; Nay: Nayarit; Oax: Oaxaca; Pue: Puebla; QRoo: Quintana Roo; SLP: San Luis Potosí; Tlx: Tlaxcala; Ver: Veracruz; Yuc: Yucatán; Zac: Zacatecas.

In the results, some states are the main origins of honey, sending large quantities to other destinations, whereas others do not allocate honey to any destination in the model. This does not indicate a lower production capacity in those states, but rather the result of an optimization process to reduce transportation costs.

For instance, Aguascalientes distributes 173.3 t of honey to Guanajuato, while Baja California Sur sends 20.1 t to Baja California. Similarly, Guerrero and Hidalgo have significant allocations to Mexico City, with 1,019.7 t and 617.6 t, respectively. This pattern suggests that destinations with the highest demand, such as Mexico City and the State of Mexico, receive large amounts of honey from various origins, reflecting the high demand in these metropolitan areas.

On the other hand, states such as Yucatán, Campeche, Veracruz, Oaxaca, Quintana Roo, and Colima did not have honey allocations within the model, which could be explained by the high transportation costs associated with these origins. Since the goal of the model is to minimize total logistics costs, allocations are preferentially distributed from the lower-cost origins to the destinations with the highest demand. The absence of allocations from these states does not necessarily imply that they have a lower production capacity, but rather that the costs of transportation to the destinations considered are higher compared to other origins, which makes it not economically viable to make these shipments.

The allocation mentioned in the previous paragraph in the states of Yucatán, Campeche, Veracruz, Oaxaca, Quintana Roo, and Colima indicates an overproduction (16,307 t) compared to national demand, which has led these states to export most of their production. Thus, they have become exporters due to the surplus of honey. Likewise, the excess honey in Jalisco and Chiapas (6,311 t), not destined for domestic demand, reflects a supply higher than national needs. In this context, opening new international markets or improving transport logistics conditions could allow these states to take advantage of their surplus, supplying foreign markets with greater demand and more competitive logistics costs.

In addition to its economic relevance, logistics optimization has major environmental implications. In particular, reducing transportation costs not only decreases economic expenditure, but also contributes to the mitigation of greenhouse gas (GHG) emissions. This is due to the direct correlation between fuel consumption and the distance traveled per tonne transported. For example, on routes where the model allocates honey from nearby sources or with better infrastructure to demanding centers, an indirect reduction in the carbon footprint is achieved. Similarly, the elimination of unnecessary or inefficient routes helps to minimize the environmental impact associated with the use of cargo vehicles.

This type of analysis is essential for the design of more sustainable supply systems, especially in the context of the growing global concern about climate change and the need to move towards circular economy models. However, it is important to recognize that any logistics system involves certain environmental impacts. Consequently, future studies could extend the current analysis through tools such as life cycle assessment (LCA) or detailed emissions assessments, considering variables such as the type of transport used, the energy efficiency of fleets, and the conditions of the vehicle fleet in each region.

Conclusions and implications

In 2020, Mexico experienced a surplus of 24,527 t of honey, consolidating itself as one of the largest producers and exporters worldwide. Nonetheless, domestic consumption remains low, with an average of 194.6 g per capita, indicating that, despite the high production, honey is not fully exploited in the domestic market. Although there are variations in production between states, it is important to recognize that factors such as environmental conditions, vegetation type, and producer characteristics significantly influence the amount of honey generated in each region. For example, states such as Jalisco, Yucatan, and Chiapas possess favorable conditions for greater honey production, whereas other states, such as Mexico City, rely heavily on imported honey. This reflects a fragmented market in which high logistics costs, especially in peripheral regions with limited infrastructure, affect both domestic consumption and international competitiveness. The optimal distribution model reveals that the most economical transport routes concentrate shipments, leading to disparities in distribution. To improve competitiveness, it is essential to optimize transport infrastructure, reduce logistics costs, and facilitate access to both domestic and international markets. States with surpluses have the potential to increase their share of global trade, especially if export routes are improved and producers' competitiveness is incentivized. In the long term, investment in infrastructure and the reduction of logistical barriers could open up opportunities in high-demand international markets, strengthening Mexican honey exports.

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