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Optimizing the distribution of mango (*Mangifera indica*) production in Mexico

Otimização da distribuição da produção de manga (*Mangifera indica*) no México

Optimización de la distribución de la producción de mango (*Mangifera indica*) en México

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ABSTRACT

One of the main problems mango growers face in Mexico is the efficient distribution of the product from the production areas to the different markets in the country and border points for the export of surpluses. Therefore, the present work aims to formulate a delivery model that minimizes the transportation cost and ensures that the mangoes arrive at their destination promptly and freshly. Using a delivery model makes it possible to achieve the objective by optimizing the proposed routes and modes of transportation for an open economy. The model showed that mango demand is fully supplied, and a surplus is exported. According to transportation costs, it was also found that the best-located production center is Campeche, and the most poorly-located production center is Nayarit.

Keywords: Delivery model, cost reduction, mango, Mexico, production, distribution optimization.

RESUMO

Um dos principais problemas enfrentados pelos produtores de manga no México é a distribuição eficiente do produto das áreas de produção para os diferentes mercados do país e para os pontos de fronteira para a exportação do excedente. Portanto, o objetivo do presente trabalho é formular um modelo de transporte que minimize os custos de transporte e garanta que as mangas cheguem ao seu destino em tempo hábil e frescas. Com o uso de um modelo de transporte, é possível atingir o objetivo otimizando as rotas de transporte e os modos de transporte propostos para uma economia aberta. O modelo mostrou que a demanda por manga é totalmente suprida e que há um excedente que é exportado. Também foi constatado, de acordo com os custos de transporte, que o centro produtor mais bem localizado é Campeche e o centro produtor mais mal localizado é Nayarit.

Palavras-chave: Modelo de transporte, manga, México, custo mínimo, centros produtores, centros consumidores, distribuição.

RESUMEN

Uno de los principales problemas a los que se enfrentan los productores de mango en México, es la distribución eficiente del producto, desde las áreas de producción hasta los distintos mercados del país y puntos frontera para exportación de los excedentes. Por lo tanto, el objetivo del presente trabajo es formular un modelo de transporte que minimice el costo de transporte y garantizar que los mangos lleguen a su destino de manera oportuna y fresca. Mediante el uso de un modelo de transporte, es posible lograr el objetivo mediante la optimización de las rutas de y modos de transporte propuestos para una economía abierta. El modelo arrojó que se abastece en su totalidad la demanda de mango y que se tiene un excedente el cual es exportado. También se encontró de acuerdo con los costos de transporte que el centro productor mejor ubicado es el de Campeche y el centro productor más mal situado es Nayarit.

Palabras clave: Modelo de transporte, Mango, Mexico, costo mínimo, centros productores, centros consumidores, distribución.

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Mango distribution optimization
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The study provides a cost-effective distribution model for mango growers in Mexico, ensuring timely and fresh delivery, thereby improving market access and profitability.
Originality/value:
This research introduces a relevant delivery optimization model for mango distribution in Mexico, enhancing supply chain efficiency and supporting export strategies.

INTRODUCTION

In the case of mango, in Mexico agricultural producers follow complicated routes to reach consumers in their sales and in some cases unnecessary trips are made, in addition to that, as in many cases happens, the participation of intermediaries means that they obtain the greatest part of the profits by bringing the product to the consumer at a high price.

The lack of knowledge of what has to be done to export or a better sale and distribution of mangoes, as well as the requirements to be met to be able to access better brands, government support that encourages them and advice to venture into best practices without the need for so many intermediaries (Astudillo-Miller et al., 2020; Ramos et al., 2019).

One of the main problems of agricultural products in Mexico is the inefficient distribution and marketing of these products, added to this the costs and transportation routes in addition to the intermediaries, therefore, it is necessary to carry out adequate planning on the problems of distribution and marketing of mango in Mexico.

Another important item is that mango is a perishable crop, so it must have shorter and more economical transportation routes to be able to reach consumers in good condition and with the quality required for consumption.

Proper selection of supply chain structure improves quality, logical performance, responsiveness, efficiency, and demand fulfillment (Orjuela-Castro et al., 2017)

Identify the optimal transportation routes from production centers to consumption centers with the help of a minimum cost delivery model for mangos in Mexico using linear programming, with which seek to find a distribution model for mango in Mexico that allows minimizing transportation costs and ensures timely supply at the main supply centers in the country.

Ideally, you want to find the influence between strategy and structure. The importance of strategy selection for a supply chain taking into account the type of product and chain; As mangoes are a perishable and seasonal product where their period is short and the demand is highly sensitive and unpredictable, several authors (Agarwal et al., 2006; Ben Naylor et al., 1999; Gattorna, 2009; Lee, 2002), they have studied and proposed up to 4 lean, agile, fully flexible and continuous replenishment supply chains, separately and combining them in order to improve supply chain performance, reduce the bullwhip effect and get closer to demand (Orjuela-Castro et al., 2017).

It is necessary to use logistics, which consists of the process of planning the instrumentation and control of asset flows efficiently, optimizing warehouse stock and thereby determining the flow of materials from their production origin to their final consumption destination.

Distribution problems have always existed, and various models have been developed in search of a solution of this problem, including game theory, preference theory, and mathematical models of operations that are based on integral and differential calculus.

Thus, linear programming is a methodology used to search for a maximization or minimization solution of a linear function subject to various restrictions (Bueno de Arjona, 1987).

Which allows reaching a point of optimization where producers achieve profit without having to waste the product, which in this case cannot remain in the warehouse for long periods of time. Various marketing strategies have been used to increase costs and compliance with quality methodologies.

“In Mexico, campaigns have been promoted to disseminate the gastronomic and nutritional value of mango to encourage its consumption, mainly of the varieties of commercial interest, while the varieties marketed locally lack studies that promote the promotion of their consumption due to the contribution nutritional-functional and that allow adding value to the productive chain (SUMAYA MARTINEZ et al., 2012).

The characterization of agri-food products in Mexico has sought various distribution routes, however, one of the main challenges is the management of distances and with it the handling of the product so that its quality can be guaranteed upon delivery.

"One of the compounds that can give additional value to this fruit are natural antioxidants, which are widely distributed in fresh plant foods and their products, including vitamin E, vitamin C, carotenoids and phenolic compounds, specifically flavonoids (Ercisli et al., 2008; Maldonado-Astudillo et al., 2016).

The identification of the benefits of the product in conjunction with the quality brings with it the need for commercial evaluation, in the first instance the distribution, although it is possible to identify the states that have higher consumption rates and the producers, it is necessary to propose routes of access that allow costs to be minimized.

In this way, it is possible to calculate and identify the areas where greater production is required or, conversely, a decrease, depending on its surplus or deficit.

MATERIALS AND METHODS

The collection and analysis data on supply and demand is crucial to implement an effective transportation model. These data include information on the location of mango production areas by state of the republic, the quantity of mangoes produced and the demand for mangoes by state, as well as the location of the main supply centers throughout the country.

Linear programming is a very useful planning method for making decisions that require a choice between many alternatives for decision making.

The main components of a linear programming model are the objective function, a set of restrictions and another set of non-negativity conditions (Alvarado Boirivant, 2011).

Transportation Model

Transportation is one of the problems that can be solved with linear programming. This problem consists of determining the appropriate (optimal) routes through which the quantities of product will be transported from the producing centers to the consuming centers. This means developing a transportation model in which the distances and costs for this concept are minimal. Likewise, the total volume of product considered in each center of origin must be transferred to each consumption center (Antonio-Gonzalez et al., 2012; Ayllon Benítez et al., 2015).

To find the optimal solution with linear programming, it is necessary to approach the problem in mathematical form, which is why it is necessary to have the following information.

- ✓ Quantity of product existing in each center of origin or production.
- ✓ Quantity of product demanded by each of the consumption centers.
- ✓ Shipping distances per unit between all possible routes from origin and destination centers.

The design of the model to minimize transportation costs includes economic variables and the demand for consumer centers was determined, as well as the production capacity of each state and the cost of transporting a ton of product to the areas with a deficit (Ayllon Benítez et al., 2015). Mathematical model for the transportation model:

Minimize $Z=d_{11}X_{11}+d_{12}X_{12}+d_{13}X_{13}+\ldots+d_{1m}X_{1m}$

$d_{21}X_{21}+d_{22}X_{22}+d_{23}X_{23}+\ldots+d_{2m}X_{2m}$

. . . .

. . . .

. . . .

$d_{n1}X_{n1}+d_{n2}X_{n2}+d_{n3}X_{n3}+\ldots+d_{nm}X_{nm}$

Subject to: $X_{11}+X_{21}+X_{31}+\ldots+X_{n1} = C_1$

$X_{12}+X_{22}+X_{32}+\ldots+X_{n2} = C_2$

. . . . .

. . . . .

. . . . .

$X_{n1}+X_{n1}+X_{n1}+\ldots+X_{nm} = C_n$

$X_{11}+X_{12}+X_{13}+\ldots+X_{1m}\leq k_1$

$X_{21}+X_{22}+X_{23}+\ldots+X_{2m}\leq k_2$

. . . .

. . . .

. . . .

$X_{n1}+X_{n2}+X_{n3}+\ldots+X_{nm} \leq kn$

In general form it would be:

Minimize $Z = \sum_{j=1}^{n} \sum_{j=1}^{n} d_{ij} x_{ij}$

Subject to: $\sum_{j=1}^{n} x_{ij} = c_j$

Where:

d_{ij} = distances of sending a unit of product from the i-th center of origin to the j-th center of destination.

x_{ij} = quantity of product that is sent from the i-th center of origin to the j-th center of destination.

c_j = quantity of product demanded from the j-th consumption center.

k_j = quantity of product that exists in the i-th center of origin or production.

It's important note that:

When supply is greater than demand, the supply restrictions must be inequalities with the sign (≤) and the demand restrictions would be equalities. When supply and demand are equal all restrictions will be equal.

The information necessary for the formulation of the transport model is the follows:

- Quantity of surplus product existing in each of the centers of origin.
- Quantity of product demanded by each of the destination centers.
- The cost incurred to move the product from the producing centers to the consuming centers, in our case, will be the distances from the centers of origin to the centers of destinations (Alvarado Boirivant, 2011).

LINDO 6.1 computer package system

Transportation model: The delivery model seeks to determine a transportation plan for a commodity from several sources to several destinations. The model data is:

1. Level of supply at each origin and the amount of demand at each destination.

2. The unit transportation cost of the merchandise to each destination.

Since there is only one commodity, a destination can receive its demand from one or more sources. The objective of the model is to determine the quantity that will be sent from each source to each destination, such that the total transportation cost is minimized.

Statistical information required:

Production in tons of the selected crop in the last year (2020) by state.

State population:

Apparent consumption per capita of 12.7k. (STATISTA, 2023).

Local consumption in the state = population X consumption per person.

State production – local consumption.

Identify the surplus quantities if the result of the previous line is positive and consider the surplus as the quantity to be transported to other states. If the previous difference is negative, that quantity is brought from other entities.

Separate into a list of bidders with their respective surplus quantities (what should be transported to other entities) and in another column the states and their deficit quantities (what they require to be brought from other states)

Identify points of origin of the surplus areas (a city in the producing area) and destination points (a city considered a regional commercial center)

Group product destination centers to facilitate the transportation model according to their location and easy access, locating the supply center for each region.

Group producing states into the same origin if these states have a common producing region of the product in question and define the city of origin.

Main mango producing states in Mexico

According to SAGARPA, mango is produced in 23 states, of which 10 contribute 98 percent of the total national production. The origin states (X_i) for the states whose production is greater with respect to their internal consumption, have a surplus, on the other hand, the destination states (X_j) are the states that cannot cover their demand with internal production, they have a deficit. The origins were taken from the most important producing area of each state with a surplus and for the destinations, the most important supply centers of each destination state were taken as reference.

The variable X_{A1} corresponds to the origin Los Mochis, Sinaloa and destination supply center the Toluca, Estado de Mexico, X_{A2} from Sinaloa to CDMX, ..., the variable X_{J25} with origin in Amatitan, Jalisco with destination to the port of Veracruz. Two border points were taken into account since at the national surplus in mango production and this surplus is exported to more than 20 countries, with the United States of America being the main buyer, the border points are the Port of Veracruz ($X_{i\,25}$) and the Nuevo Laredo II border bridge, Tamaulipas ($X_{i\,24}$)

Transportation costs were estimated from the trial version of the GlobalMap Software "Autotransport Routes of México 2023". They were calculated for a T3-C2 type transport which, according to NOM-012-SCT-2-2017, has a capacity of 30 tons (GlobalmapMexico, 2023).

Table 1. Classification of states (offers and demanders)

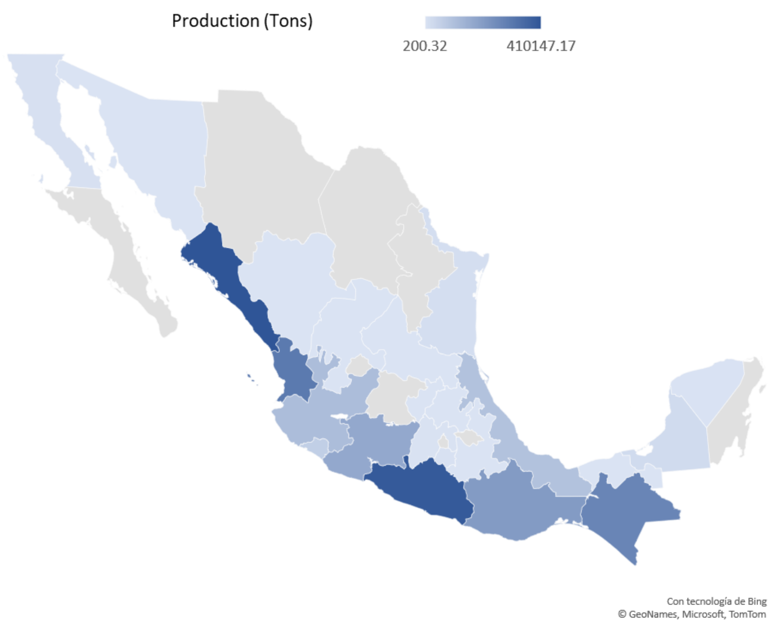
STATE	POPULATION	PRODUCTION	TOTAL CONSUMPTION	OFFERER	DEMANDING
SINALOA	3026943	410147.17	38442.18	371704.99	
WARRIOR	3540685	395477.31	44966.70	350510.61	
NAYARIT	1235456	304618.62	15690.29	288928.33	
CHIAPAS	5543828	270644.12	70406.62	200237.50	
OAXACA	4132148	207709.72	52478.28	155231.44	
MICHOACAN	4748846	170580.16	60310.34	110269.82	
COLIMA	731391	59081.74	9288.67	49793.07	
CAMPECHE	928363	23852.59	11790.21	12062.38	
JALISCO	8348151	110916.5	106021.52	4894.98	
MEXICO	16992418	3002.66	215803.71		212801.04
CDMX	9209944		116966.29		116966.28
PUEBLA	6583278	532.73	83607.63		83074.9
GUANAJUATO	6166934		78320.06		78320.06
NEW LION	5784442		73462.41		73462.41
CHIHUAHUA	3741869		47521.74		47521.73
COAHUILA	3146771		39963.99		39963.99
BAJA CALIFORNIA	3769020	7999.61	47866.55		39866.94
GENTLEMAN	3082841	510.08	39152.08		38642
SONORA	2944840	619	37399.47		36780.46
SAN LUIS POTOSI	2822255	330	35842.64		35512.63
TAMAULIPAS	3527735	13638.16	44802.23		31164.07
QUERETARO	2368467	208	30079.53		29871.53
TABASCO	2402598	1099.27	30512.99		29413.72
YUCATAN	2320898	1777.81	29475.40		27697.59
QUINTANA ROO	1857985		23596.41		23596.4
DURANGO	1832650	1348.41	23274.66		21926.24
ZACATECAS	1622138	200.32	20601.15		20400.83
MORELOS	1971520	4967.1	25038.30		20071.2
AGUASCALIENTES	1425607		18105.21		18105.2
TLAXCALA	1342977		17055.81		17055.8
B. SOUTHERN CALIFORNIA	798363		10139.21		10139.21
VERACRUZ	8062579	96490.1	102394.75		5904.65
TOTAL	126014024	2085751.18	1600378.10	1543633.13	1058258.88

Source: Own elaboration with data from (Diario Oficial de la Federación, 2017; GlobalmapMexico, 2023; INEGI, 2023; SAGARPA, 2022; SIACON, 2023; SIAP.SAGARPA, 2023).

Estimating of supply and demand for mango in Mexico

To perform the calculation and classification of each of the states of the Mexican Republic, the data obtained from SAGARPA will be ordered, from which the population by state, production and per-person consumption of mangoes, taking into account the above. The pertinent calculations are carried out to determine whether it is a supplier or a demander, determining the total consumption of each state and with this, if it has a surplus in production it is a supplying state and if, on the contrary, it consumes more than what it consumes, it is a demander state, once determining whether each state is a supplier or a demander, the states are classified to facilitate the structure of the minimum cost transportation model.

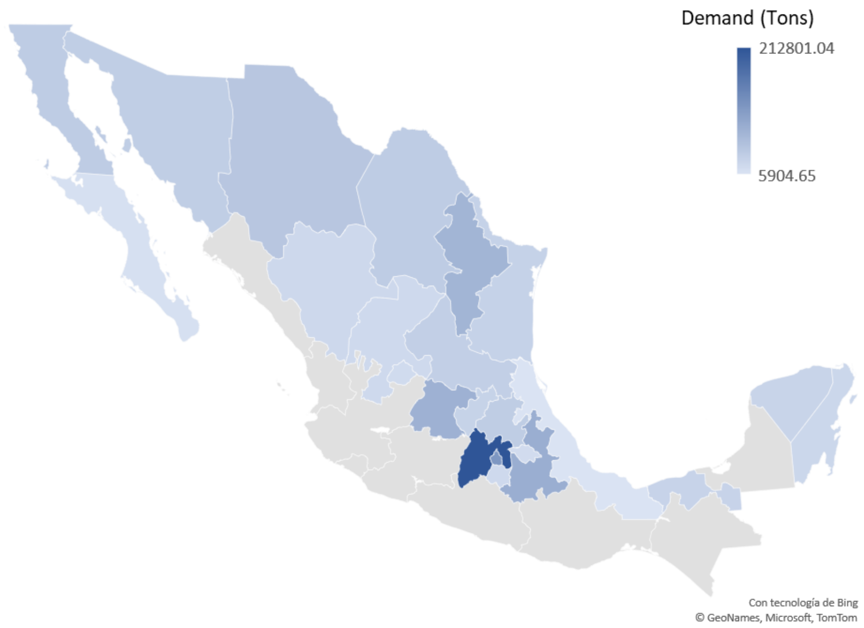
Figure 1: Main mango producing states tons, 2020.



Source: Own elaboration with data from (INEGI, 2023; SAGARPA, 2022).

The main Mango producing states in Mexico are Sinaloa (20%), Guerrero (19%), Nayarit (14%), Chiapas (13%), Oaxaca (10%), between these five states they accumulate 76 percent of the National Production.

Figure 2: Main Mango demanding states (Tons)



Source: Own elaboration with data from (INEGI, 2023; SAGARPA, 2022; SIAP.SAGARPA, 2023).

The states that, even though mango is produced in 23 states of the country, are not able to cover their internal demand and require purchasing mango from other states that have a surplus, being the State of Mexico (20%), CDMX (11%)

Puebla (8 %), Guanajuato (7%), Nuevo León (7%), the main claimants, these five states covering more than 50% of the mango that is demanded from other producing states to supply their demand.

Table 2: Transportation costs from production centers to consumer centers ($/Ton.)

OFFERERS/DEMANDS	SINALOA	GUERRERO	NAYARIT	CHIAPAS	OAXACA	MICHOACAN	COLIMA	CAMPECHE	JALISCO
MEXICO	917	198	559	725	270	233	442	721	344
CDMX	986	199	607	667	213	271	505	664	407
PUEBLA	1058	266	690	589	135	337	571	586	473
GUANAJUATO	761	400	382	908	453	94	274	904	174
NUEVO LEON	815	594	704	1007	686	397	593	1004	493
CHIHUAHUA	455	879	752	1464	1010	681	822	1464	722
COAHUILA	589	648	486	1209	754	410	551	1205	452
BAJA CALIFORNIA	711	1669	1087	2350	1898	1431	1397	2349	1263
GENTLEMAN	967	251	588	676	222	247	481	673	383
SONORA	128	1165	496	1758	1315	847	813	1765	680
SAN LUIS POTOSI	649	367	486	878	423	145	3. 4. 5	874	245
TAMAULIPAS	883	545	689	792	465	526	582	788	482
QUERETARO	819	298	440	794	340	113	332	791	2. 3. 4
TABASCO	1419	567	1040	279	298	698	932	202	834
YUCATAN	1708	805	1328	567	586	975	1221	80	1122
QUINTANA ROO	1690	785	1310	439	568	968	1203	188	1104
DURANGO	416	586	305	1132	677	333	612	1128	478
ZACATECAS	554	472	449	987	543	199	341	983	241
MORELOS	1042	161	674	672	217	339	555	668	457
AGUASCALIENTES	613	470	384	987	533	136	278	984	176
TLAXCALA	1043	265	674	610	155	321	556	606	457
BAJA CALIFORNIA SUR	949	1992	1320	2583	2139	1671	1637	2579	1491
VERACRUZ	1294	447	915	350	218	572	807	346	709
NUEVO LAREDO	946	710	836	1148	817	539	725	1144	625
PORT OF VERACRUZ	1193	400	824	459	161	471	717	467	618

Source: Own elaboration with data from (FAO, 2023; GlobalmapMexico, 2023)

RESULTS AND DISCUSSION

The value of the objective function is 650,503,700. Which is expressed by multiplying the transportation cost by the tons transported on each route.

This indicates that, when optimizing the program, it is the minimum cost generated by transporting mango production from the production centers to the consumption centers. However, to obtain the optimal value mentioned above, the model must meet certain established conditions, which, in this case, are the selected choice variables that are expressed in the first column (VARIABLE) of the program´s output sheet.

The variables that have a value (VALUE) different from zero are those that were selected and that become part of the optimal solution, referring to the transportation routes that must be carried out to reduce total costs to a minimum, and their value indicates the tons that must be transported on each active route, the model considered the following activities.

Mango production in Mexico for 2020 has a surplus of more than 480 thousand tons, which are exported to various countries since Mexican mango has a strong demand worldwide and has great potential to continue increasing its production taking advantage of the privileged location that provides favorable conditions for its cultivation.

Continuing with the analysis, the solution for the restrictions appears in the program output; the column (ROW) is found in the first place, which indicates the number that corresponds to each restriction.

Table 3: Product distribution (active routes) that generate the minimum mango transportation cost (Ton).

CONSUMER CENTERS	PRODUCTION CENTERS								
	SINALOA	GUERRERO	NAYARIT	CHIAPAS	OAXACA	MICHOACAN	COLIMA	CAMPECHE	JALISCO
MEXICO			161339			32287	19175		
CDMX		116966							
PUEBLA		83075							
GUANAJUATO			78320						
NEVO LEON	73462								
CHIHUAHUA	47522								
COAHUILA	39964								
BAJA CALIFORNIA	39867								
GENTLEMAN						38642			
SONORA	36780								
SAN LUIS POTOSI							30618		4895
TAMAULIPAS			31164						
QUERETARO						29872			
TABASCO				29414					
YUCATAN				15635				12062	
QUINTANA ROO				23596					
DURANGO	21926								
ZACATECAS	20401								
MORELOS		20071							
AGUASCALIENTES			18105						
TLAXCALA		7586				9470			
BAJA CALIFORNIA SUR	10139								
VERACRUZ				5905					
NUEVO LAREDO	81643								
PORT OF VERACRUZ		122812		125688	155231				

Source: Own elaboration with data from the output of the model in LINDO 6.1 (LINDO, 2007)

Offer restrictions

First, restrictions 2 to 9 will be interpreted, which refer to the mango production available in each producing center to offer to the consuming centers. In the column (SLACK OR SURPLUS), which is interpreted as the amount of mango that was left over or missing with respect to those offered or demanded. The restrictions that have a value different from zero represent the quantities of the product required to satisfy the demand by the different consumer centers, but in the case of supply this column indicates the volume of mango that was left over in those producing centers or that was missing for be able to satisfy consumer demand.

As can be seen, all the restrictions have a value of zero, which indicates that all production was distributed to cover the country's internal demand and the surplus was exported by sending it to the border points of Puerto de Veracruz and the Nuevo Laredo II Border Bridge in Tamaulipas.

According to the shadow prices (DUAL PRICES) of the restrictions, they indicate how much the value of the objective function would increase or decrease if production were increased by an additional ton in any producing region and shipped to any of the consumer centers. According to the results, taking restriction 9 (ROW 9) as an example, if there were one more mango unit in the Campeche production center and it was transported to any consumer center considered, the value of the objective function decreases by 974.

Demand restrictions

Within the results, the restrictions (ROW) from 12 to 33 are analyzed, which correspond to the quantity of mango demanded by the producing centers. The model yielded the following:

The demand for mango in all the consumer centers contemplated in the work is satisfied.

Considering shadow prices (DUAL PRICES), restrictions that have a value equal to zero in the SLACK OR SURPLUS column are restrictive resources. In the model, all restrictions are restrictive. It is interesting to know what would happen if the consumer center of Mexico demanded one more ton of mango? This can be answered with an example, in restriction 1 1 (ROW 11), by increasing the quantity demanded in Mexico by one ton and being satisfied, the value of the objective function would increase by 723, and thus it could be analyzed for any restriction of demand.

In economic terms, the most advisable restrictions are those that increase the objective function by the least value, thus the total cost would rise in a smaller proportion. These restrictions are 20 and 27, which correspond to the states of Sonora and Durango since shipments from those states would increase the total cost by only 128 and 416 pesos, respectively.

Sensitivity analysis

The second part of the report, which breaks down the results of the LINGO package, shows the sensitivity analysis, both for the coefficients of the objective function and for the RHS of the constraints. This allows to know the ranges in which these values and the restriction levels can fluctuate, with the aim that the basic solution does not present any type of modification, which are within the acceptable parameters.

CONCLUSIONS

The distribution of agricultural products is not only a problem at the national level, since there is no monetary capacity to carry out studies that allow farmers to speed up distribution routes, in general support to the countryside limits the actions and implementation of techniques that improve quality within the functions. however, it is one of the main sources for ensuring a country's food security.

There are countries with less development than Mexico and where mangoes are also produced, such as Burklina Faso, Mali and Ivory Coast, classified among the poorest in Africa in which there is a significant number of producers who not only export fresh and dehydrated mangoes mainly to the European Union, but also market them with organic and fair trade certification to special markets (Springmann et al., 2018; van der Waal & Zongo, 2011; Vayssières et al., 2014).

The national production of mango in Mexico in 2020 was sufficient to satisfy domestic consumption, which is why exports of this product were carried out, considering for the model two of the main border points outbound products from Mexico, one on the border with the United States, which is one of the main demanders of Mexican Mangoes and another point in the port of Veracruz as a shipment to send mangoes to Europe.

According to the results obtained in the transportation model and based on the objectives set out in the study, the following conclusions emerge:

- ✓ The use of linear programming is effectively a useful tool to determine the minimum transportation cost in mango cultivation since it allows the product to be distributed among consumer centers at the lowest possible cost.
- ✓ The formulated model is the one that yields the minimum distribution cost of mango among the different consumer centers that were considered for the preparation of this research.
- ✓ According to the output of the model, the routes for the transportation of mango in the Mexican Republic those shown in table 3, which indicates the tons required to be shipped from each production center to the consumer center.
- ✓ The production centers best located with respect to consumer centers are Sinaloa, Michoacán, Campeche, Jalisco, since they are the producing states that exhaust production in its entirety according to the output of the model.
- ✓ The best strategically located consumer center is Sonora since if it were to demand one more unit of mangoes the objective function would increase only 128.

The mechanisms of a dynamic integration of supply, as proposed by (Orjuela Castro et al., 2016), coincide with the results of this research, despite the fact that the countries are different, since the integration of integration mechanisms into the supply chain suggests that there would be a lower loss of fruit from the warehouse, that is why the optimization of transport becomes a determining factor not only for the reduction of costs but also to ensure that the demand for mangoes is covered throughout the national territory.

Recommendations

- ❖ That the distribution of mango in Mexico follows the structure proposed here obtained with the help of the proposed model
- ❖ To carry out similar studies, it is advisable to apply the methodology proposed in this work, since it is a simple procedure to handle and guarantees optimal distribution of any type of product.

- According to the results obtained, it is recommended to increase production in the states that placed all their production, since they are very well located strategically, although currently only with the results of the model it would not be feasible because the supply is greater than the demand but if Taking into account the international market, it is very feasible and profitable, in addition to the fact that the mango is a perennial plant and takes several years to start producing, thinking about the future it would be a very good alternative.
- Another alternative for the use and management of the mango surplus that is available in the states of Sinaloa, Nayarit, Oaxaca, and Guerrero, would be to establish mango industrializers, with the purpose of preserving the mango in different presentations for longer and facilitating its handling as well as diversify their presentation.

Researchers, government organizations, and policymakers can benefit from the findings of these types of studies by taking appropriate steps to increase farmers' incomes, balance market supply and demand, and reduce losses in other perishable fruits (Rajvardhan Kiran et al., 2023).

As in India, which is the main producer of mangoes in the world, this type of study can be taken as a basis for those in charge of formulating and generating public policies for the benefit of producers and the population in general, to achieve the maximization of the benefit-cost of both producers and final consumers.

Complying with a transport optimization model will allow in the future to increase the request for a greater quantity of the product and open the way to foreign distribution fields with a greater solidity, for which the availability of producers would have to be reconsidered to adapt to new commercial routes, implementing distribution models focused not only nationally but also locally.

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