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Effect of the price of yellow maize (*Zea mays* L.) imports on animal protein consumption in Mexico

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ABSTRACT

Objective: to determine the effect of the price of yellow maize imports on animal protein consumption, through time series analysis, to provide empirical evidence of the effect of trade policies on the animal protein consumption by the population in Mexico.

Design/Methodology/Approach: the Food Trade Dependency Index (FTDI) was calculated to measure the degree of dependence on imports of this grain. Data from the National Survey of Household Income and Expenditure (ENIGH in Mexico) were used to account for household expenditure on consumption of beef, chicken meat and pork, eggs, and milk, in three basic baskets of goods. Regressions were performed with the Autoregressive Vector (ARV) method and Granger causality tests.

Results: results indicated that variations in the price of yellow maize imports have a direct impact on the price of animal protein. This, in turn, can affect Mexico's population access to essential sources of animal protein, especially in low-income households.

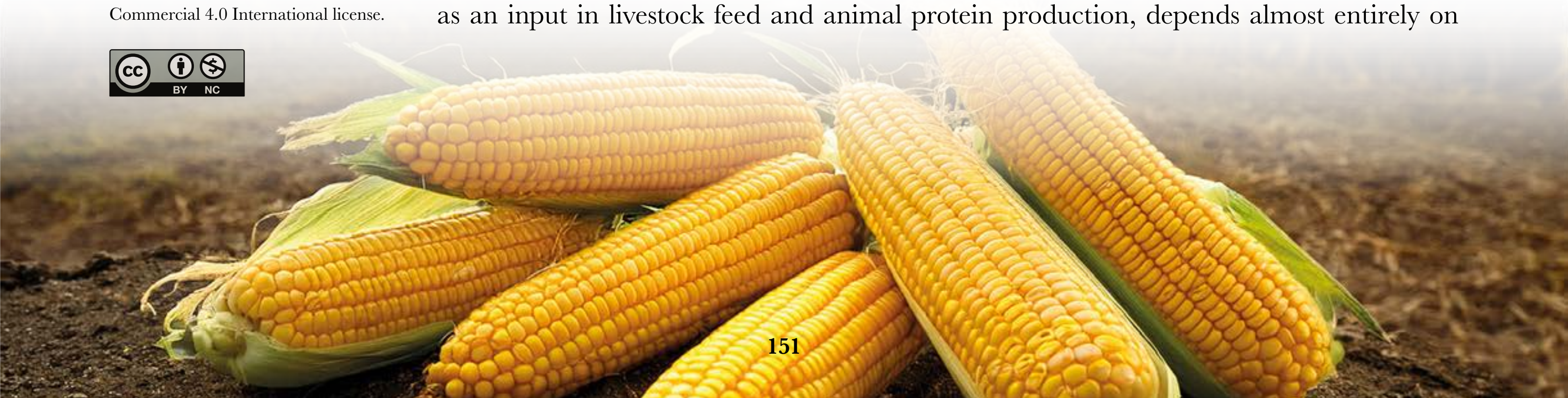
Limitations/Implications of the study: this research did not consider other factors that can also influence the price of animal protein; such as, production costs, domestic demand and seasonal variations in protein consumption. This fact can limit the comprehensive understanding of the causal relationship found with the study variables.

Findings/Conclusions: this research highlighted the vulnerability of the Mexican agrifood industry to international trade dynamics. It also underlines the importance of designing strategies to enhance competitiveness in the domestic production of yellow maize.

Keywords: competitiveness, apparent national consumption, food trade dependency.

INTRODUCTION

Maize is a fundamental component in Mexico's agrifood system, not only because of its cultural and social importance, but also because of its strategic role in the diet of the population and in the livestock industry. In 2022, Mexico produced around 27 million tons (Megagrams, Mg) of maize, of which 90% corresponded to white maize intended mainly for human consumption (FAOSTAT, 2024). However, demand for yellow maize, used as an input in livestock feed and animal protein production, depends almost entirely on



imports (SIAP, 2024). This dependence generates economic vulnerability to fluctuations in international prices of yellow maize, which can have a significant impact on the production costs of basic food products. In this regard, Zahniser *et al.* (2019) mentioned that Mexican imports of yellow maize are used for industrial processing, mainly for diets in the production of beef, pork, chicken meat, eggs, and milk.

The basic basket of goods for Mexicans includes food products derived from animals that are fed with yellow maize. So, it is interesting to study the relationship between maize imports and the prices of products in the basic basket of goods, as they would be directly influencing inflation levels in the country. In the current national context, since the decree on February 13, 2023 (DOF, 2023) that prohibits imports of genetically modified maize for direct human consumption, this supply is limited in Mexico's national territory, which aggravated vulnerability in terms of food security. Over the years it is observed that the national consumption, covered only by domestic production, is continuously decreasing (Figura 1).

According to García-Salazar *et al.* (2023), the Food Trade Dependency Index can be expressed as the proportion of imports in relation to ANC. The value of this indicator went from 15% in 1994 to 36% in 2022, which is mainly due to the low maize prices that were caused by the trade preferences established in the North American Free Trade Agreement (NAFTA), then ratified in the current United States-Mexico-Canada Agreement (USMCA). In the period from 1994 to 2022, Mexico's national production, consumption and imports grew 46%, 104% and 492% respectively, which is consistent with the calculations of the degree of food dependency in the same period.

In this research, the effect of yellow maize imports on the consumption of animal protein *per capita* was determined, through time series analysis, to provide empirical evidence of the effect of trade policies on the animal protein consumption by the population of Mexico. The hypothesis states that changes in imports of yellow maize

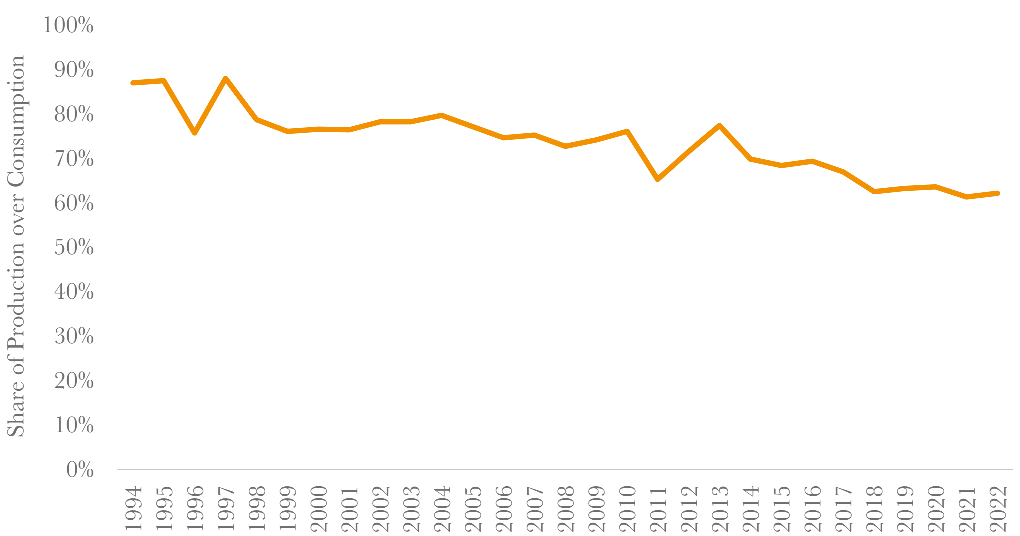


Figure 1. Share of production in the Apparent National Consumption (ANC), from 1994 to 2022. Source: prepared by the authors using data from FAOSTAT (2024).

are related to changes in the price of animal protein, and therefore to the national consumption of this protein *ceteris paribus*.

MATERIALS AND METHODS

Information data sources

Data collection was done through official sources. In the case of trade flows, two sources were used: i) Database of the United States Department of Agriculture (USDA, 2024) which allowed obtaining information on trade between the United States and Mexico, and ii) Database of the United Nations Food and Agriculture Organization (FAOSTAT, 2024), from which the total trade flows of each country were obtained, and also, homogenized information on production.

The data for the characterization of Mexican production (yield, production volume, and irrigation use) were obtained from the agricultural end-of-cycle database of Mexico's Agrifood and Fisheries Information Service (SIAP, 2024). The average annual expenditure that households make on food goods was determined. Data for this estimation were obtained from results of the Mexico's National Survey of Household Income and Expenditure (ENIGH, 2022), by the Mexico's National Institute of Statistics and Geography (INEGI, 2024).

For the terms of this research, we accounted for the average household expenditure in three different basic baskets of goods (Table 1). In addition, the average expenditures per household on chicken meat, beef, pork, eggs, and milk, were considered individually. Data processing was performed in the econometric software STATA© 17.

In 2005, due to a demographic reconciliation caused by the II Count of Population and Housing 2005 at the request of Mexico's Secretariat of Social Development under the Federal Government, INEGI deployed the extraordinary survey of the ENIGH 2005 (INEGI, 2005). Since the information reported in 2004 was incomplete, the data presented in that year were discarded, and the information of 2005 was used twice, as if it were from 2004.

Table 1. Characteristics of the basic baskets of goods that were used.

	Basic basket (DOF)[1]	Basic basket (SEGALMEX)[2]	Food basket (CONEVAL)[3]
Purpose	Established for measuring inflation through the Consumer price index.	Established for assuring the access of the poor to basic foods.	Established by The National Council for the Evaluation of Social Development Policy (CONEVAL) in order to measure food poverty. It calculate the cost of satisfaying the minimum caloric requirements of an individual.
Composition	Contain fifty three products including food, cleaning items, personal hygiene items.	Contain forty products including corn, beans, rice, eggs,milk and non food items.	Take into account only food items considering nutrition recomendations.

Source: elaborated by the authors based on the Official Gazette of the Mexican Federation (DOF, 2020), the Mexico's Secretariat of Agriculture and Rural Development (SADER, 2019), and CONEVAL (2022). From this point on, these will be referred as 'Canasta DOF'[1]; 'Canasta 40 (SEGALMEX)'[2] and 'Canasta Alimentaria'[3].

Food trade dependency index

The Food Trade Dependency Index (FTDI) is an indicator that measures the degree to which a country depends on imports to meet its domestic food needs (García-Salazar *et al.*, 2023). The FTDI is particularly useful in contexts such as Mexico, where imports of basic foodstuffs, such as maize, have increased significantly, affecting food self-sufficiency and access to affordable food of the most vulnerable population (FAO, 2024).

The calculation of the FTDI was done based on the methodology used by the United Nations Food and Agriculture Organization (FAO, 2010) to calculate the trade dependency index on cereal imports (%). Other authors (García-Salazar *et al.*, 2023; Hernández *et al.*, 2023) have used this index to address issues of food security and international trade. According to FAO & Banco Mundial (2021), this methodology can be complemented with statistical data-collection tools and multidimensional assessment models to identify vulnerabilities associated with international trade and their impact on national food systems.

The calculation of the food trade dependency index responds to the following expression:

$$FTDI = \frac{M}{(P + M - X)}$$

where, M: volume of imports, P: domestic production, and X: volume of exports, of yellow maize.

Within the context of this research, the FTDI reflects the relationship between the volume of yellow maize imports and its apparent national consumption. So, the higher the quotient, it is interpreted as a greater food trade dependency on imports.

Data interpolation

The ENIGH data are collected every two years; so, 16 observations were obtained in the study period 1994-2022. According to Harrell (2015), to guarantee reliable results and avoid problems such as multicollinearity during the estimation of the econometric model, it is desirable to have between 10 and 20 observations for each estimated parameter. In addition, some complex techniques, such as structural equation models (Bentler and Chou, 1987) or autoregressive vector models (ARV) require larger sample sizes (Hamilton, 1994).

Therefore, in order to strengthen the time series to achieve statistical consistency in the estimators, we used interpolation of the data (Arévalo-Ovalle *et al.*, 2021) for the average consumption expenditure on chicken meat, beef, pork, eggs, milk, and those in the three basic baskets of goods previously described. In this way, the time series was composed of 29 annual observations for each variable. The linear interpolation method was used because the data showed an almost linear behavior among the available observations.

Autoregressive vector models (ARV) and causality in Granger's sense

According to Hamilton (1994), ARV models are especially useful when i) we seek to analyze the intertemporal and bidirectional relationship among several endogenous variables; ii) there is not clearly defined economic or structural theories; or iii) the aim is to analyze how one variable responds to a "shocking event" in another variable, and how this effect propagates over time.

Once the ARV model has been estimated, it can be used to identify and understand the mechanisms by which the effects of the variables included in the model are transmitted (Rossi & Wang, 2019). This analysis can be performed by means of a causality test, and be complemented by the analysis of impulse-response functions. All of which allows examining how a shock in one variable affects the others over time (Guerrero, 1987).

The Granger causality test, proposed by Clive W. J. Granger in 1969 is used in econometrics and time series analysis to evaluate whether past information from one time series helps to improve predictions of another time series, beyond what could be predicted using only past information from the second variable.

The available data on the average import prices of yellow maize, the information collected from the ENIGH, and the objective of this research are consistent with the characteristics described above that make plausible the estimation of an ARV model, and the application of the Granger causality analysis.

The determination of the order of the ARV model was delimited through the Akaike Information Criterion-AIC (Akaike, 1974), which penalizes complex models to avoid overfitting. This means that although a more complex model may better fit the data, the AIC introduces a penalty for using more parameters, this feature is useful in contexts where sample sizes are limited (Hurvich & Tsai, 1989).

RESULTS AND DISCUSSION

The FTDI was calculated to determine the level of dependence that Mexico has on imports of yellow maize. Figure 2 shows the evolution of the index during the study period (1994-2022).

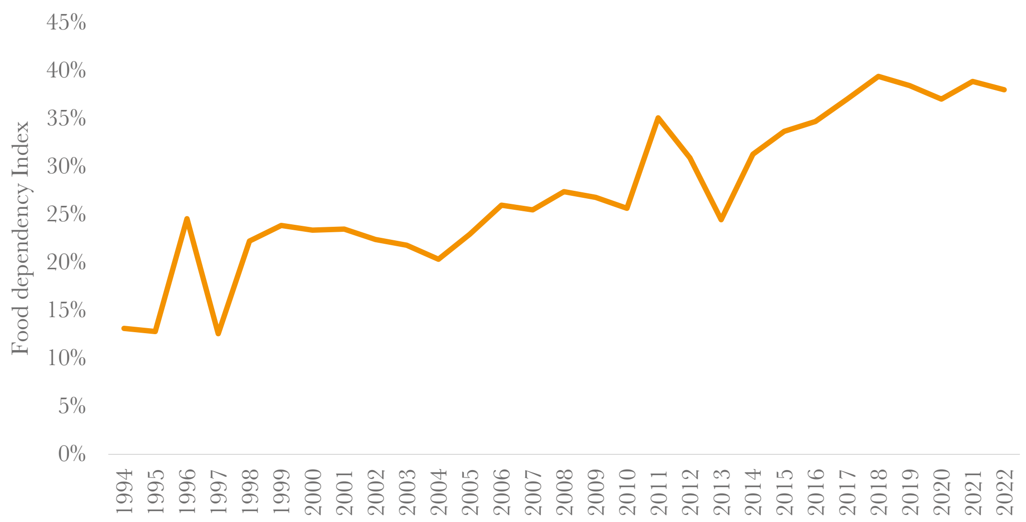


Figure 2. Evolution of the Food Trade Dependency Index (FTDI) of yellow maize in Mexico in relation to the United States, 1994-2022. Source: elaborated by the authors with data from FAOSTAT (2024) and USDA (2024).

According to FAO (2010), in situations in which the FTDI value is greater than 25%, the analized country is interpreted as being at critical levels of food dependence. Only in the years 1994 to 2005 did the FTDI not exceed that value.

During the period 2000-2010, it is observed that although there was a growth in dependence on imports, this value only exceeded the maximum limit established by FAO (2010) by two percentage points. In that space of time, NAFTA (recently, USMCA) fostered a more robust trade flow between Mexico and the U.S., allowing the latter to be consolidated as Mexico's main supplier of yellow maize.

From 2011 onwards, there has been a significant increase in the FTDI, with values close to 40%, due to the almost total absence of national production of yellow maize. According to Cruz Herrera *et al.* (2021), recent policies that seek to promote food self-sufficiency in Mexico have had a limited impact on reducing this dependence.

Based on that analysis, the specification of an ARV model was proposed in which the average price of yellow maize imports was estimated as an explanatory variable, and the average consumption expenditure on proteins from animals fed with imported yellow maize were estimated as explained variables. Those are chicken meat, beef, pork, eggs, and milk; in addition, the average expenditure in the three basic baskets of goods mentioned was included. The average expenditures per household in those three selected basic baskets of goods were analyzed (Table 2).

Table 2. Average expenditure per household (MXN $) in three selected basic baskets of goods (1994-2022).

Year	Basic basket (DOF)	Δ %	Basic basket (SEGALMEX)	Δ %l	Food basket (CONEVAL)	Δ %
1994	2403		255		236	
1996	1991	−17.2	377	48.2	314	33.0
1998	3105	56.0	511	35.6	421	34.0
2000	3091	−0.4	649	27.0	524	24.3
2002	2512	−18.7	960	47.9	713	36.1
2005	2632	4.8	1269	32.2	802	12.5
2006	2311	−12.2	765	−39.7	571	−28.9
2008	2295	−0.7	832	8.7	956	67.6
2010	912	−60.2	778	−6.4	669	−30.1
2012	3608	295.4	1314	68.8	848	26.9
2014	3535	−2.0	1095	−16.6	811	−4.3
2016	3835	8.5	1232	12.5	943	16.2
2018	4990	30.1	1320	7.1	1476	56.5
2020	6457	29.4	1759	33.3	1363	−7.6
2022	6685	3.5	2172	23.5	1701	24.7
Average	3357	22.6	1019	20.1	823	18.6
Standard Deviation	1604	0.83	515	0.28	420	0.29
Standard Error	414	0.22	133	0.08	109	0.08

MXN $: Mexican pesos. Source: generated by the authors with data from the ENIGH (2024).

A substantial difference can be observed in the averages and standard deviations, especially in the data of the basic basket 'Canasta DOF', which can be explained by the inclusion of goods that are not essential for certain segments of the population. The percentage variations and volatility of the data indicate that price and consumption dynamics have been particularly sensitive to macroeconomic events such as economic crises or inflation. Since abrupt falls in expenditure in the three baskets from 2009 to 2010 are observed, reflecting the decrease in the median of real labor income as part of the effects from the 2008-2009 economic crisis in Mexico. Likewise, according to data from the Bank of Mexico (2024), the increase in the costs of the three baskets, especially in recent years, reflects a direct impact of inflation on the prices of basic goods.

The years 1996, 2002 and 2008 showed that households, despite had reduced their expenditures on the basic basket 'Canasta DOF', which refers to the broadest basket of goods studied; they in fact increased their spending on 'Canasta 40 (SEGALMEX)' and 'Canasta Alimentaria'. Therefore, the demand for basic foodstuff has an inelastic behavior compared to basic non-food goods.

The average household expenditure on livestock products as a proportion of expenditure in the 'Canasta Alimentaria' basic basket was analized to understand the relative importance of each product over time, regardless of the growth or decrease in total household expenditure. Likewise, the total of the joint participation of these goods for each year analyzed is presented (Table 3).

Fluctuations in percentage share reflect the influence of economic factors, such as income, prices, and changes in the accessibility of these products (Martínez *et al.*, 2019).

Table 3. Percentage share of average household expenditure on livestock products within the 'Canasta Alimentaria' (the basic basket including only foodstuff).

Year	Chicken*	Beef*	Pork*	Eggs	Milk	Total
1994	1.5	4.3	3.2	0.7	1.6	11.3
1996	2.0	5.3	3.5	1.0	2.4	14.2
1998	2.1	5.3	3.4	1.2	2.0	14.0
2000	2.1	4.6	3.4	1.0	1.8	12.9
2002	2.8	4.4	3.1	1.1	1.9	13.3
2005	3.8	5.0	3.2	5.6	2.8	20.5
2006	5.4	7.4	4.2	2.1	3.0	22.1
2008	3.4	4.9	2.9	1.5	2.0	14.7
2010	5.5	7.4	4.5	2.1	3.0	22.6
2012	4.1	24.8	5.9	6.7	2.7	44.1
2014	9.6	9.2	6.5	2.9	3.3	31.5
2016	5.4	9.9	4.6	3.5	4.9	28.2
2018	4.6	12.7	4.0	2.8	2.5	26.5
2020	8.1	12.6	6.4	3.1	2.8	33.0
2022	5.7	8.8	5.2	3.4	3.7	26.9
Average	4.3	8.4	4.2	2.5	2.6	22.1

Source: elaborated by the authors with data from the ENIGH 2022. *Data included expenditures on raw meat for household consumption, these do not include prepared or processed meals.

Beef continues to be the product with the greatest weight in expenditure, although its variability highlights the need to observe its behavior compared to other more accessible products such as chicken meat or eggs.

The Akaike Information Criterion (AIC) was used to determine the optimal number of lags in the estimation of the ARV model. In general, the lag with the lowest AIC value for each variable was selected. The results indicated that, of the eight dependent (explained) variables analyzed, two showed an optimal lag in the second period; three, in the third; and the remaining three, in the fourth period. This selection sought to ensure the best specification of the model. In all cases, the exogenous variable used was the average price of yellow maize imports.

Values of the coefficients for each regression in the ARV model are shown (Table 4). In the causality test in Granger's sense, the calculated values of the χ^2 (Chi square) statistic are presented. Statistical significance is noted in parentheses.

The statistical significance of the regressions shows that the lag coefficient in the ARV models for the variables 'Canasta DOF', 'Canasta 40 (SEGALMEX)', and 'Canasta Alimentaria', expenditure on chicken meat, expenditure on beef, expenditure on eggs, and expenditure on milk was statistically significant with ($p \leq 0.05$). Therefore, the average price of imports of yellow maize had a relevant impact on these dependent variables.

In all regressions, the expected sign of the coefficients was positive as expected, because the increase in the price of yellow maize was transferred to higher prices in livestock products. However, the total expenditure on these products was not significantly reduced because the demand for these products responds more quickly to changes in other factors; such as, taste and preferences, changes in substitute products, and consumer incomes (Purcell, 2000).

Regarding causality in Granger's sense, there was significant evidence ($p \leq 0.01$) that, lags in the price of yellow maize cause changes in all dependent variables. The values of the χ^2 (Chi square) statistic were high; statistical significance of each estimate allowed us to ensure valid results. In this way, it was possible to demonstrate causality in Granger's sense of the price of yellow maize imports on the expenditure for those goods selected in this

Table 4. Results of ARV model regressions and causality tests in Granger's sense.

Variable	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4
Basic basket (DOF)	16.61	15.3	15.08	15.002*	15.03
Basic basket (SEGALMEX)	14.09	12.84	12.52	12.55	12.39*
Food basket (CONEVAL)	12.94	12.05	11.94	11.61	11.59*
Chicken spending	8.33	0.54	7.46	7.05*	7.1
Beef spending	10.34	9.77	9.34*	9.4	9.37
Pork spending	7.81	6.12	5.85*	5.92	5.99
Egg spending	8.06	7.59	7.23	7.21	7.04*
Milk spending	6.58	6.02	5.64	5.5*	5.58

Source: elaborated by the authors with data collected from the ENIGH (2022) and USDA (2024) processed with the STATA© 17 software.

research. Our hypothesis is accepted that changes in imports of yellow maize are related to changes in the price of animal protein, and therefore to its consumption. Thus, trade dependence makes the stability of the prices of the basic basket vulnerable. Despite what was found by Orozco-Cirilo *et al.* (2023), in the case of the price of maize (per bushel) and the prices of Mexican pork, who reported a non-significant relationship after performing multiple regressions.

Yellow maize is one of the main components in the feed of the animals used for protein production (Castillon, 2021), those that were chosen in the set of goods analyzed in our research. In livestock production systems, feed represents around 60 to 70% of the costs (Núñez, 2017); therefore, causality in the consumption of basic goods of livestock origin, on the part of the price of the input, is congruent. Beckman *et al.* (2024) showed that pursuing food security for maize in Mexico could increase maize prices by 24.8%, also that Mexican households would have to spend between 6.7% and 13.9% more on food.

The growing percentage of SEGALMEX strategic products, in the basic basked of food products, indicates that more and more consumption in Mexico is destined to the most essential good, which is food. This can be interpreted as a loss in the purchasing power of households. It was proved that yellow maize imports cause, in Granger's sense, variations in the consumption of selected livestock products. Such a transmission of variations is consistent with another study (González & Martínez, 2015), which determined that the price of maize was causal in the tortilla price, because unit transmission elasticity was found between the two price series.

CONCLUSIONS

Causality was demonstrated in Granger's sense. Thus, the prices of yellow maize imports explain the variations in the expenditure on livestock products. Trade policies and fluctuations in the international prices of yellow maize may have a direct impact on the economic access of households to livestock products. Also, trade variations can also affect producers, particularly those with lower purchasing power. The increase in spending on animal protein from livestock farming in Mexico is closely linked to the dependence on imports of yellow maize as a key input in livestock farming.

This signifies structural vulnerability of the Mexican agrifood sector to fluctuations in international trade, which can compromise the sustainable access to livestock-origin food in the medium and long terms. Moreover, if there were significant increases in import prices. Thus, we emphasize the importance of generating strategies to reduce the levels of dependence on imports of yellow maize, in order to guarantee food security, economic feasability, and, indirectly, social stability in Mexico.

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