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The social and economic impact of agave waste utilization in Mexican liquor industries

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Abstract
This paper intends to evaluate the social and economic impact of agave waste utilization (leaves) derived from the production of agave spirits (AS): tequila, mezcal and bacanora. This includes a brief description of the nature and Geographical Indication of those industries and their close relation to the map of poverty and migration to USA. Data is presented on the instability of: prices, production volumes of raw material (stems) and final product (tequila), due to long maturation periods of agave. Proforma mass and economic balances of leaf utilization favor agave fiber (*ixtle*) decortication to the production of high added value of artisanal products. Forthcoming environmental restrictions of plastics in food industry will increase the demand of such kind of products. Economic balances support the promotion of local textile industries based on ixtle but they would require bottom-up promotion of small self- reliant enterprises instead of the most unsuccessful top-down paternalistic approach.

Keywords: agave waste, ixtle, recycling, social impact, economics.

Background

AS, such as, tequila, mezcal and bacanora, are made by distillation of fermented fructose syrups which in turn are obtained by steam cooking of agave mature stems, rich in fructans [1]. They are produced in regions labeled as Geographical Indications[1] (GI). Tequila GI is in the states of Guanajuato, Jalisco, Michoacán, Nayarit and Tamaulipas; mezcal GI is in the states of Durango, Guanajuato, Guerrero, Michoacán, Oaxaca, Puebla, San Luis Potosí, Tamaulipas and Zacatecas; and, bacanora GI is in 35 municipalities in the eastern mountains of Sonora (Fig. 1). According to the "*Consejo Regulador del Tequila*" [2], in the period from 1995 to 2017, the average annual tequila production, obtained from the harvest of 17,400 ± 4,600 hectares of agave, yielded 203 ± 68 million of liters, obtained from the cooking of 704 ± 268 thousand Mg of stems, and was linked to the waste of approximately 500,000 Mg of leaves. The production trends of raw materials (stems) and product (tequila) showed nearly periodic fluctuations around an average linear growth (Fig. 2), generating cycles of approximately 10 years that are related to the maturation time of the agaves. On the other hand, the simultaneous plot of stem prices and their production volumes shows opposite trends, where periods of low production values seem to coincide with periods of high prices, but with some delays between the peaks of prices and the low volumes of stem production (Fig. 3). These data are consistent with the cobweb theorem where primary producers planting new agaves have important uncertainties about the future condition of the mature stems market, this being the structural basis of the sustained instability between supply and demand as discussed by Macías-Macías [3]. Large tequila distilleries have tried to regulate the price of liquor, storing a large fraction of their surpluses and thus dampening the price fluctuations of AS and, they also promote long-term contracts with agave stem producers [3] to stabilize the price of raw materials. One alternative way to dampen market fluctuations is to diversify the use of products or by products of a given crop. For example, the profitable use of agave leaves that now rot in the fields but could be utilized as raw materials to produce fibers and feedstuffs. Thus, stem producers would have another income source that will encourage them to maintain and reproduce agave plantations despite the fluctuations on the stem price paid by the distillers.

Ecology, Poverty and Agave production

Half of Mexican territory is arid land because the two major mountainous chains (Western and Eastern Sierras Madre) act like giant condensers of the humidity blown by the sea winds into mainland Mexico. Therefore, a significant fraction of Mexican peasantry is bound to live in regions where annual water precipitation is lower than 400 mm, especially in the mountainous regions where irrigation projects are not feasible. In such regions, natural evolution produced a very rich biodiversity of plants belonging to the family of *Crassulaseae* that, according to Nobel [4], are five times more efficient to fix CO_2 per mole of water, as compared to the conventional C3 or C4 plants, such as, cereals or sugar cane. Archeological evidence from the arid region of La Quemada, Zacatecas, has shown that agave plants were cultivated at least more than one thousand years ago [5] and it has been speculated that cooking agave stems was an ancient way to survive when corn harvest was lost during a severe drought [6].

Analysis of the major endpoints of USA remittances to Mexican families shows a remarkable coincidence with most of the areas of commercial agave exploitation as shown by Fig. 4. This includes some of the tequila regions in Jalisco and Guanajuato, as well as mezcal regions in Guerrero, Guanajuato, Michoacán, Oaxaca and Puebla. Such coincidence seems related to the relative aridity of the land because it poses serious problems of survival with small parcels and a meager maize production. Mexican fieldwork has shown that families in some of those areas often supplement their income by harvesting and selling agave stems to local distilleries, but they seldom use the leaves for any practical purposes, despite the ancient traditions related to the use of agave fibers although there is now a demand for ropes, bags and other ixtle items distributed through Internet [7].

Peasant families have combined, for centuries, the production of corn, beans, agaves and grass to feed themselves and their livestock (calves, lambs or goats). Also, they harvest agave stems, either cultivated or wild, to be sold to local distilleries at a low price. As mentioned above, most of tequila large distillers, have long term contracts with stem producers but, in the case of mezcal and bacanora, there are many small family distilleries that produce AS with low efficiencies, and sell their AS at relatively low prices. This economic situation is quite common in the mountainous agave regions of Durango, Guerrero, Oaxaca and Sonora, that are very conflictive due to the competing and illegal production of poppy flowers gum (opium) or marihuana (hemp). Hence, any productive and commercial alternative increasing the income of lawful activities by rural families, is a positive step to reduce poverty and to compete with the clandestine emigration to USA or to reduce the negative social effect of drug traffickers.

Mass and economic balances of agave stem and leaf utilization

[1] According to World Intellectual Property Organization (WIPO) a Geographical Indication is a sign on the label of a product that shows is made in a given region with well-defined features related to that region.

Agave stems and leaves have 20% of dry mass of which, 80% are fructans and, 20% are fiber with pectin and other materials [8]. Mass balance of ethanol fermentation from stems can be expressed as a conversion factor of kilograms of stem required to obtain one liter of 38^{o} GL liquor. The stoichiometric conversion factor with 100% efficiency is estimated to be 3.3 kg/L (300 L/Mg). Industrial production of tequila is converging to a practical conversion of 4 kg/L equivalent to 82% efficiency (Fig. 5). Apparently, this has been achieved using advanced substrate extraction, fermentation and distillation processes. On the other hand, mezcal and bacanora traditional distilleries have conversion figures between 10 kg/L and 20 kg/L with equivalent efficiencies down to 33% or even 17%, respectively. Such inefficiencies place a burden on the benefit to cost ratio because artisanal distilleries need more stems than modern tequila factories, although they sometimes compensate inefficiency with higher final selling prices, since mezcal and bacanora can be distinguished from tequila by different aromatic patterns as shown by "electronic nose" analysis [9]. A fraction of AS is made from wild agave plants, especially for bacanora, and in these cases, agave stems are collected by a small team of distillers leaving the leaves to rot in the hills. However, wild agave reserve is being depleted and the current governmental trend is to promote sustainable plantations with increasing production costs. Therefore, the use of agave leaves is for the time being, restricted to agave plantations, because it would be impractical for the small distilleries that produce AS with wild agave.

Table 1, shows the estimated mass balance of fructans and fibers per 1,000 kg of wet stems where stems are 56.3% and leaves 43.7% of total above ground biomass [10]. Estimated total dry mass is close to 20 Mg/ha which is similar to the agave productivity measured by Nobel [4]. Therefore, around 7 Mg of fructans and 2 Mg of ixtle fibers are wasted as leaves by each hectare of harvested agave for tequila production, amounting more than 150,000 Mg of usable raw materials in more than 17,000 ha.

Ixtle can be recovered by decortication of agave leaves using a variety of machines ready available in Mexico. The yield is around 4% on wet basis and the most popular products are ixtle bags weighing 0.2 kg to 0.3 kg, advertised by internet with retailing price between 5.3 USD to 15.9 USD [11].

Fructans can be recovered as a residue from agave leaf decortication, fermented to lactic and other small chain organic acids and used as feedstuffs for ruminants. Santos *et al*. [12] have shown that sisal decorticated by-products can substitute half of the intake of corn silage without reducing the feed efficiency of lamb production reported between 4 kg to 6 kg of dry mass intake per kg of live weight gain (25% to 16% efficiency). Other reports found lower efficiencies with conversion factors near to 8 (kg intake)/(gain weight kg) [13]. These low feed efficiencies reduce the profitability of animal production because the price of live weight is around 3 USD/kg [14].

When comparing alternatives for agave leaves utilization is worth noticing that utilization of fibers as textiles has a much higher added value than utilization of fructans as a fodder. This can be estimated from the retailing price of ixtle finished products (50 USD/kg) as compared to a lower price of livestock. Taken as a reference 1,000 kg of stems with 4% content of fiber and 16% content of fructans and assuming conversion figures of 80% for fiber and 25% for fructans, the final sales figures are, 2,000 USD for fiber products and 120 USD for livestock production. This justifies the choice of fiber transformation as the main product to be considered in this work.

Market perspectives for new uses of agave fibers

Agave leaves have been used for centuries as a source of long fibers such as, henequen (sisal) or ixtle (Tampico fiber) from *A. sisaliana* and *A. lechuguilla*, respectively. Unfortunately, those industries decayed by the introduction of petrochemical polymers. However, recent trend against plastic pollution [15] and climate change is pushing for replacement of chemical polymers by natural fibers. For example, the campaign Clean Indian Mission (*"Swachh Bharat Abhiyaan"*) includes the substitution of plastic by jute bags in the tourist areas [16]. Pranab Mukherjee, President of India, declared that this situation "opened up window of opportunity for enhanced use of jute" [17]. In California, Proposition 67 [18] banned the use of grocery plastic bags and reduced plastic liter by more than 70% [19]. In Mexico, every year 250,000 Mg of plastic films are used as food envelopes with a market value of 200 million USD [20].

The above indicated 4% yield of ixtle fibers from leaves multiplied by the estimated 500,000 Mg of leaves derived from AS produces an estimate of 20,000 Mg of ixtle fibers to be recovered from currently wasted leaves. Thus, assuming ten times reuse of ixtle bags with a selling price of 10 USD/kg there is room to replace plastic bags used in supermarkets by ixtle bags made from solid waste of AS industries. Recent inquiries in supermarkets and pharmacies of Ciudad Obregón, Sonora, showed the presence of traditional bags and cleaning products made with ixtle with average selling prices above 55 USD/kg. This shows that ixtle fibers have not disappeared from the Mexican market despite the decline of sisal and ixtle production. In this research, a field visit was made to Celutex, a Mexican factory at Matehuala, S.L.P. that uses ixtle as raw material and is introducing innovative designs and production schemes for the national market (Fig. 6) but is hindered by the scarce supply of fibers obtained from the harvest of wild *Agave lechuguilla*. Recent tests in Celutex showed that the leaves of cultured *Agave angustifolia* Haw. produce the same yield and quality of fibers as compared to leaves of wild *A. lechuguilla*. Those observations opened the way to use wasted leaves from mezcal or bacanora, but with the same machinery as the one used for conventional ixtle fibers. Leaves from *Agave tequilana* are similar to leaves from other *Agave sp.* used in AS production. Therefore, there is room for textile industrialization of agave fibers associated to the production of AS throughout Mexico with a potential market size of more than 100 million USD.

Socio economic impact of diversification of agave utilization

Bowen and Valenzuela-Zapata [21] have discussed that tequila GI has not produced much benefits to agave producers, despite the commercial success of large distilleries, because the conversion of traditional peasant units of integrated agriculture into contract monoculture systems, has reduced agave biodiversity, degraded local environment and diminished the quality of tequila. To explore the potential impact of agave leaves as input to ixtle cottage industries we have looked at the present market situation of such products. Figure 4 shows that agave stem prices have been between 0.14 USD to 2.0 USD per kg and ixtle bags are sold by Internet at a price between 17.7 USD to 53 USD per kg. Bulk fiber is harvested and sold by peasants at the bulk price of only 0.53 USD per kg. Thus, textile products are retailed by internet at a price much higher than the bulk fiber price paid stems or bulk fiber. Table 2 shows some estimated economic comparisons between fiber utilization sold in the bulk or sold as textile product, as compared to the sales value of stems. Given the disparity between fiber in bulk and textiles prices, the effect of selling fiber in bulk would be negligible for the rural producer as compared to much higher sales figures when transformed into textile product. This in turn, supports the need to promote locally owned textile industries supplied with agave fibers, to compensate for the strong fluctuations of stem prices. Otherwise, the rural producers would not be encouraged to sustain agave plantations when the stem prices fall, and tequila and other AS industries would remain with fluctuations on prices and stem production, as shown in Figs. 2 and 3.

Therefore, it is worth noticing success of future small ixtle industries appears important for the stability of all AS industries because it could become a major source of income for stem producers if they have a significant participation on the revenues of ixtle textile enterprises. This in turn would support the maintenance and reproduction of agave plantations, reducing the risk factor observed by stem price fluctuations.

The importance of top-down or bottom-up projects.

Ixtle textile production can be organized at cottage level with low capital requirements because the necessary machinery is available at a low price but is necessary to discuss the social and economic feasibility of small industries, promoted and organized by two different alternatives, called top-down or bottom-up strategies. In the first case, governmental or private agencies, design, build and provide an industrial facility with little participation of the users and with practical no experience in the marketing of the final product. Users need to figure out by themselves, in a short period of time, how they are going to implement their production and commercial activities. In the second case, the farmers are induced to organized by themselves, using simple traditional techniques to be improved gradually but with emphasis on learning how to sell the finished products. Here there is a maturation period to assimilate their conversion from traditional producers to modern small entrepreneurs. Top-down and bottom-up models have been studied in rural settlements [22, 23]. In the first case, exogenous factors are predominant, while in the second of them, the needs and opportunities identified by the community (endogenous factors) lead the way for development.

In Mexico, the Ministry of Social Development (SEDESOL), is responsible for social assistance programs to alleviate the situation of people in poverty that is over 50% of the total population, being 20% in extreme poverty [24]. For this reason, since 1959, a variety of programs have been organized but with negligible impact in the reduction of this problem [25] because they have been focused on paternalistic measures instead of encouraging self- reliance of rural producers [26]. However, we have found a particularly successful project supported by SEDESOL and animated by professors of Rural Development Department of Universidad Autónoma Metropolitana at Xochimilco. This project has been sponsored by International Body Shop as an example of fair trade for ixtle products [27, 28]. It refers to the cooperative called *Ya Munts'i B'ehña* (Gathered Women), SC de RL de CV comprising the work of more than 200 indigenous (*ñahñú*) women from Valle del Mezquital in Hidalgo State (Fig. 7) who use traditional techniques to hand weave agave fibers from *Agave salmiana* to produce cleaning items to be sold in Mexico City and London beauty shops. This successful case has endured through a period of ten years and is introducing, progressively, modern processing techniques to improve their productivity. Unfortunately, the main course, mostly unsuccessful, for private or public assistance to rural areas is oriented to the top-bottom approach. Perhaps, international pressures on our society such as the threat to repatriate millions of illegal migrants from USA, and the need to fight the emergence of drug traffic, could be a new governmental motivation to support and finance the bottom-up approach that now is more the exception than the rule. Recent work in Ciudad Obregón, Sonora is oriented to the creation of a small cooperative network between commercial bacanora producers and local ixtle cottage industries, with the support of an agreement between the *Consejo Sonorense Regulador del Bacanora* and Instituto Tecnológico de Sonora (ITSON), to put in practice, the ideas developed in this paper.

Conclusions

Production of agave spirits (AS) is an important industry of Mexico with sales figures close to a billion USD using agave plants produced in arid lands and protected by Geographical Indications. However, due to agave maturation periods longer than five years, this industry has evolved with–strong alternate oscillations between the prices and the volumes of raw materials (agave stems). Such market instability affects mostly the welfare of rural producers since large distilleries have developed strategies to store the liquors and regulate the marketing of AS.

Agave leaves are the main byproduct that is wasted without profit and amounts to nearly half a million tons left to rot in the fields. Apparently the most lucrative and simple process to develop is decortication and weaving of long leaf fibers that could double the sales figures of agave and help to damp market fluctuations.

Technology and machinery to decorticate and weave agave textiles are readily available at low cost but there are two main problems: the need to reintroduce agave textiles in the national or international markets and, the problem to distribute the wealth to alleviate poverty in the arid regions of Mexico, where agaves are produced. Increasing concern on the pollution by plastic bags and envelopes is opening a new market for natural textiles that can be supplied with fibers from agave leaves but remains the problem of wealth distribution because present ixtle industries pay bulk fiber at a price 30 or 100 times lower than the retailing prices of the textile products.

Field work and present analysis has shown the need to apply a bottom-up promotional strategy to support new cottage industries involved in decortication and industrialization of agave fibers with links to commercial organizations interested in the fair trade. It is hoped that this paper helps to encourage other research and promotional teams to develop a new strategy for the sustainable use of agave in Mexico.

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Tables

Table 1 Estimated mass balance of agave stems and leaves in tequila production (Mg/ha)

Production by Item	Mg (WB)	A= Fiber (DB) Mg	B= Fructans (DB) Mg	A+B (DB) Mg	Comparison
Stems (1.00)	54.2	2.2	8.7	10.9	56.5
Leaves (0.77)	41.8	1.7	6.7	8.4	43.5
Total	96.0	3.9	15.4	19.3	100.0

WB = Wet Base DB = Dry Base

Own elaboration with information obtained from SAGARPA and Consejo Regulador del Tequila. Average stem production was calculated from 941,800 Mg of stems harvested in 17,388.6 ha. Fiber and Fructans were estimated assuming 4% and 16% content, respectively. The factor 0.77 was taken from SAGARPA data discussed by AGARED

Table 2 Estimated economic effect of fiber utilization

Mass balance	Sales (2017 USD)		
	kg	Low Price	High Price
A = Wet stems	1,000	142.0	2,050.0
B = Fiber (bulk)	40	14.8	32.0
C = Fiber (textil)	32	566.4	1,696.0
Comparisons			
100(A + B) / A		110.4%	101.6%
100(A + C) / A		498.9%	182.7%

Stem prices (USD/kg): 0.142 – 2.05 (Fig. 3 in this work)
Bulk fiber prices (USD/kg): 0.37 – 0.80 (http://www.inforural.com.mx/bajan-precio-del-ixtle/)
Textile fiber prices (USD/kg): 17.7 – 53.0 (www.mercadolibre.com.mx)

Figures

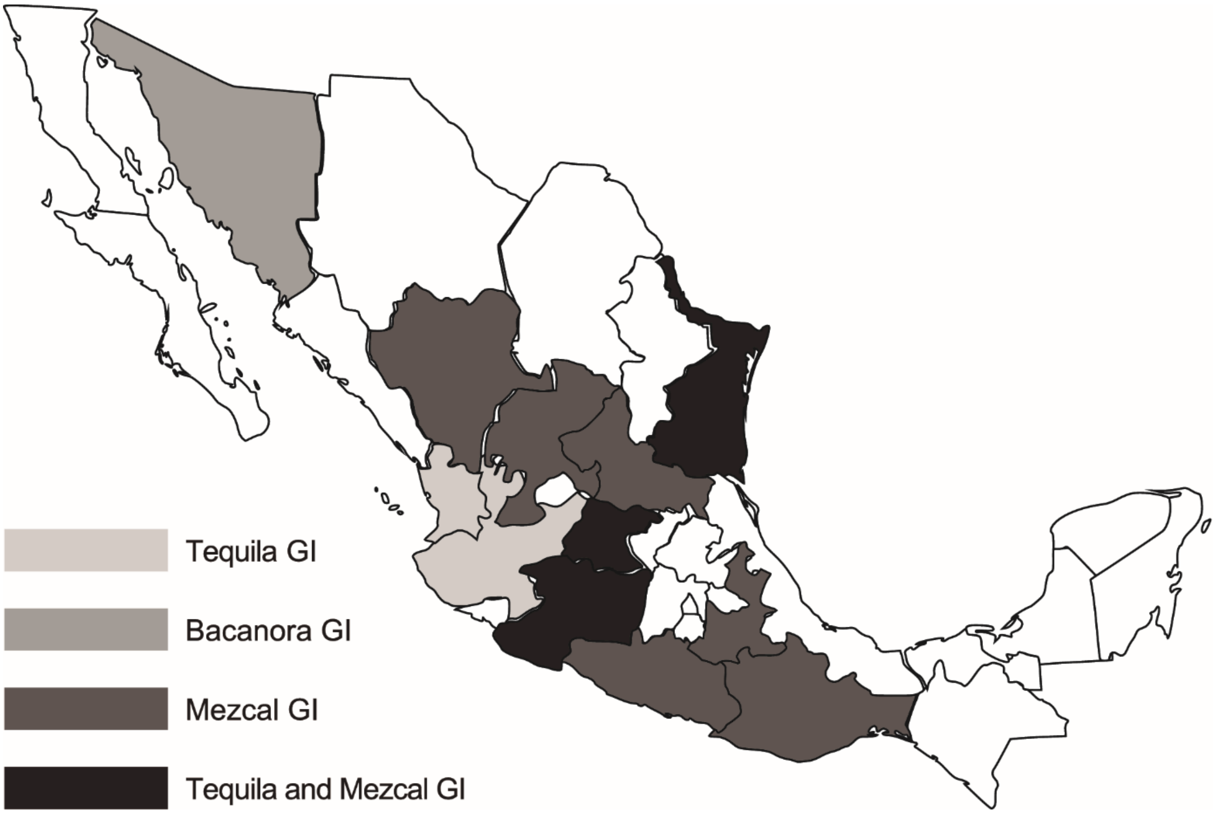

Fig. 1 Geographical Indication (GI) areas of tequila, mezcal and bacanora in Mexico. Own elaboration with information from Consejo Regulador del Tequila (https://www.crt.org.mx/), Consejo Regulador del Mezcal (https://www.crm.org.mx) and direct communication with Consejo Regulador del Bacanora

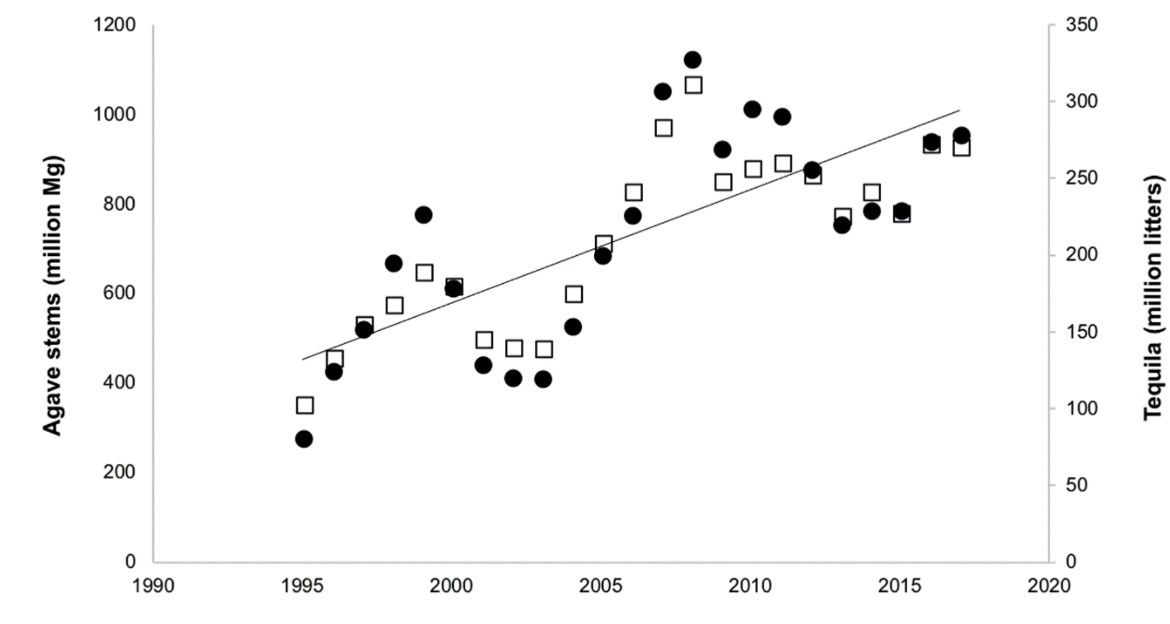

Fig. 2 Production trends of agave stems (●) and tequila (□). Own elaboration with information from Consejo Regulador del Tequila (https://www.crt.org.mx/). The oscillation period was close to 10 years

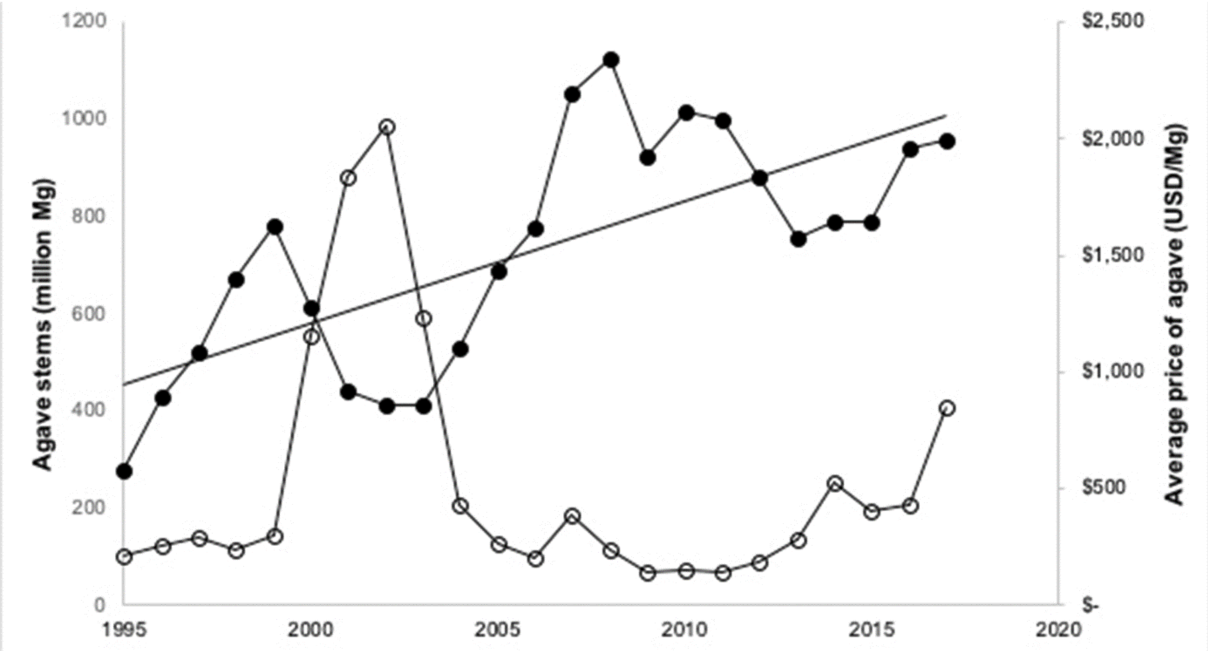

Fig. 3 Fluctuations of stem price (○) and stem production (●) in tequila industry. Solid line corresponds to the calculated linear trend of stem production. Own elaboration with information from Consejo Regulador del Tequila (https://www.crt.org.mx/) and Etatistics of agricultural production from Government of Mexico (http://infosiap.siap.gob.mx/aagricola_siap_gb/icultivo/index.jsp, https://datos.gob.mx/busca/dataset/estadistica-de-la-produccion-agricola). Prices adjusted to the exchange rate of pesos per USD according to BANXICO (http://www.banxico.org.mx/)

Fig. 4 Major endpoints of USA remittances to Mexico in 2017. Own elaboration with information from BANXICO (http://www.banxico.org.mx/SieInternet/consultarDirectorioInternetAction.do?accion=consultarCuadroAnalitico&idCuadro=CA79&sector=1&locale=es)

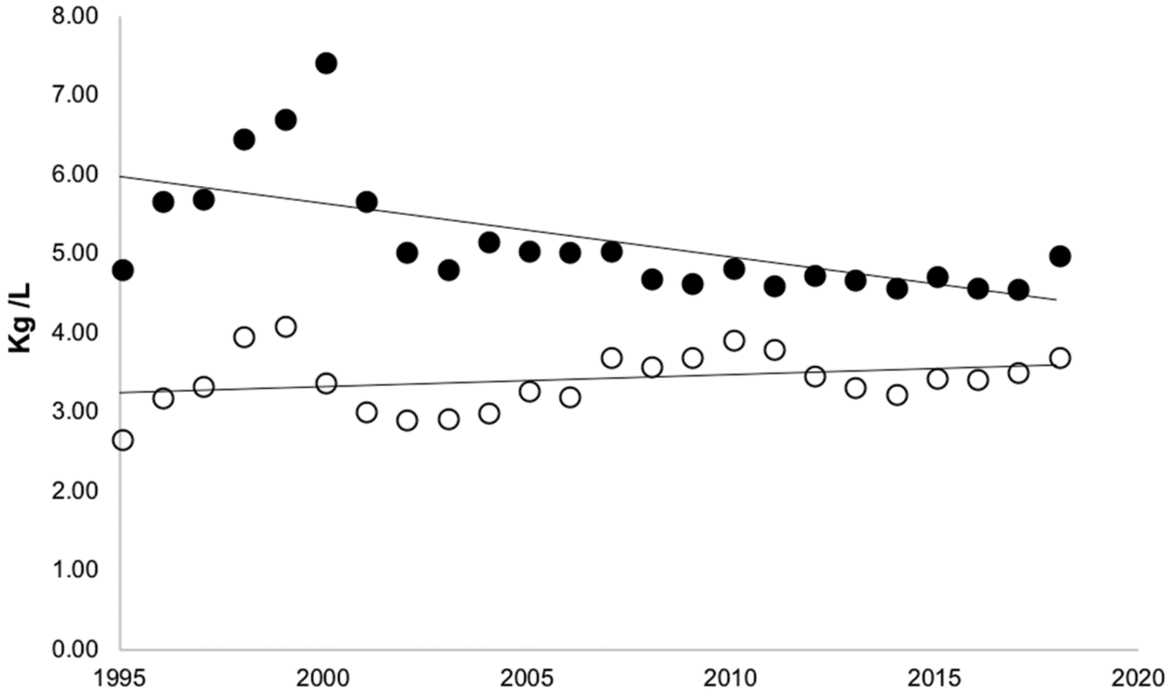

Fig. 5 Conversion trends of industrial tequila production (kg stems/Liter of tequila) for 100% agave (●) and tequila with 51% agave or more (○). Own elaboration with information from Consejo Regulador del Tequila (https://www.crt.org.mx/)

Fig. 6 Agave fiber products made by Celutex, Matehuala, S.L.P., Mexico (December 2017)

Fig. 7 Women from Valle del Mezquital, Hidalgo, Mexico (Ya Munts'i B'ehña, SC de RL de CV) working in the field to obtain agave fiber. Photograph obtained from https://www.nepibehna.com/galeria