Article

Wild plants of the center-north of Mexico with potential for oil production

Miguel Ángel Flores-Villamil[1]
Santiago de Jesús Méndez-Gallegos[1§]
Eduwiges Javier García-Herrera[1]
Alejandro Amante-Orozco[1]
Adrián Gómez-González[1]
Francisco Javier Cabral-Arellano[2]
José Fernando Vasco-Leal[3]

[1]Postgraduate College-*Campus* San Luis Potosí. Iturbide num. 73, Col. Centro, Salinas de Hidalgo, San Luis Potosí, Mexico. CP. 78600. (flores.miguel@colpos.mx; garciae@colpos.mx; aamante@colpos.mx; agomez@colpos.mx). [2]Autonomous University of Zacatecas-Academic Unit of Biological Sciences. Av. Preparatoria s/n, Col. Agronómica, Zacatecas, Mexico. CP. 98060. (fjcabral@cantera.reduaz.com). [3]Autonomous University of Querétaro-Research and Postgraduate Division-Graduate of Technological Management and Innovation-CU. Cerro de las Campanas s/n. Querétaro, Mexico. CP. 76010. (cimer@uaq.mx).

[§]Corresponding author: jmendez@colpos.mx.

Abstract

Given the fluctuation of prices and the depletion of fossil fuels, as well as their negative effects on the environment, the development and use of biofuels represent a potentially viable alternative. However, the inputs currently used in the production of bioenergy are highly questioned for their energy sustainability. Due to this, the search for alternative sources from plants resistant to adverse climatic factors, high adaptation capacity, low input requirements and not competing with food is a priority. Considering the above, samplings were carried out in north-central Mexico to collect wild species, in order to determine their productive potential, the oil content of the seeds, and analyze the physical and chemical characteristics of the oil. Seeds of 19 plant species were collected. *Agave* sp., registered the highest seed productive potential with 24 305 kg ha^{-1}; however, it has the limitation of having a long fruiting period and its oil content is low. Five of the collected seed species (*Cucurbita ficifolia*, *Cucurbita foetidissima*, *Proboscidea louisianica*, *Jatropha dioica* and *Apodanthera undulata*) reached oil contents greater than 30%. *A. undulata* could potentially produce up to 1 315 kg ha^{-1} of oil, which makes it as competitive as commercially available inputs. The physical and chemical characterization of the oils showed a wide variation, which allowed to identify oils with nutritional, bioenergetic and other potential uses.

Keywords: vegetable oil, bioenergetics, alternate energies, wild species.

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Introduction

Currently, the global energy crisis and the oscillation of the price of fossil fuels have motivated the search for new forms of less polluting energy, which gradually supplant oil as a non-renewable resource (Estrada e Islas, 2010; Romero *et al*., 2015). In this regard, Wilches (2011) points out that a more feasible alternative than oil, coal or nuclear reactors in developing countries is the direct and indirect use of energy from biomass or plant residues. The production of biofuels emerged at the end of the last century, as a strategy to promote the development of renewable, clean and sustainable energies (Agüero-Rodríguez *et al*., 2015).

Although bioenergy could improve the profitability of agriculture, promote local economic development and diversify the portfolio of productive options (Montiel-Montoya, 2010) of renewable energies, it is the most questioned and the one that has created the most controversies. It has become evident that an impact is generated around its production with economic, social, political and environmental implications, which is why, despite being a renewable energy, it is not considered, by many experts, as a non-polluting energy and therefore neither a green energy, therefore, the production of biofuels could involve more serious situations than the problem for which they were seen as a solution (Wilches, 2011). Montiel-Montoya (2010) states that biofuels can emit more greenhouse gases than fossil fuels, especially if they use crops with low yields, high fossil energy requirements or are cultivated in areas previously considered forestry.

Reyes-Reyes *et al*. (2015) point out that, in Mexico, currently the extraction of oils is made from different crops, mainly *Ricinus communis* and *Jatropha curcas*. The latter is promoted as a miraculous tree, but essential aspects of its genetic behavior, agronomic aspects, seed quality and oil yield are still unknown when they are grown under different conditions (Montiel-Montoya, 2010). Also, *R. communis* under the current conditions of production is moderately competitive and profitable in relation to other crops, so that technological improvements to the production system are required to raise their productivity, as well as increase the sale price of the raw material at a price above $500.00, so that it can be attractive to producers (Rodríguez and Zamarripa, 2013).

Mexico is considered a mega-diverse country, where it is possible to find endemic and introduced plant species that can be used in the production of biofuels; nevertheless, many ruderal, weed, ornamental and cultivated species are underutilized, due to the ignorance of their chemical components; therefore, the integral and sustainable use of these plants could increase the income of farmers in marginal areas of the Semi-arid Plateau of Mexico (Reveles *et al*., 2010). Taking into account that both native and introduced species already adapted to each region, could be used for energy purposes in those soils unsuitable for agriculture, without displacing food production and also require few inputs, this research aims to collect wild species from the center-north of Mexico, determine its productive potential, analyze its oil content and its physical and chemical characteristics, to identify plant species of oleaginous interest.

Materials and methods

Field collection

The collection of seeds was carried out through field trips between the months of June 2014 to May 2015, considering the annual availability of the plants, in 17 municipalities in the states of Zacatecas, San Luis Potosi and Aguascalientes, Mexico. The following criteria were used for the selection of the species in the field: 1) abundance; 2) seed availability; 3) accessibility to the sites; and 4) use history.

The species and the characteristics of their location are shown in Table 1. The 19 species collected in the study area are: chicalote *Argemone mexicana*, calabacilla loca *Cucurbita foetidissima*, chilacayota *Cucurbita ficifolia*, melón hediondo *Apodanthera undulata*, aceitilla *Bidens odorata*, jara *Leonotis nepetifolia*, toloache *Datura inoxia*, cardo *Datura ferox*, cadillo *Xanthium strumarium*, toritos *Proboscidea louisianica*, mostacilla *Brassica* sp., saramago *Eruca sativa*, sangre de grado *Jatropha dioica*, huizache *Acacia farnesiana*, mezquite *Prosopis glandulosa*, gobernadora *Larrea tridentata*, maguey *Agave* sp., pirúl *Schinus molle* and lampote *Helianthus annuus*.

Table 1. Characteristics and location of the species collected in the study.

State	Municipality	Latitude	Longitude	Altitude (m)	Common name
AGS	Cosío	22º23’39.8”	102º18’23.4”	2 008	Toloache
AGS	San Jose de Gracia	22º08’36.9”	102º21’26.4”	1 980	Girasol, melon hediondo
AGS	Tepezala	22º13’33.2”	102º14’14.2”	1 887	Cadillo, cardo, aceitilla
SLP	Ahualulco	22º19’38.8”	101º12’15.3”	1 862	Toritos
SLP	Salinas	22º43’56”	101º42’40”	2 096	Aceitilla, Saramago
SLP	Mexquitic	22º19’38.8”	101º12’15”	1 870	Aceitilla, Mostacilla, toritos
SLP	Mexquitic	22º16’23.4”	101º05’35”	1 980	Jara
SLP	Salinas	22º37’32.6”	101º41’15”	2 110	Toritos, girasol, saramago, aceitilla, cadillo
SLP	Venado	22º55’54.3”	101º04’25.6”	1 755	Aceitilla, cadillo
SLP	Salinas	22º35’59.9”	101º42’07”	2 115	Gobernadora, sangre de grado
SLP	Salinas	22º37’10.3”	101º43’58.9”	2 079	Huizache
ZAC	Panfilo Natera	22º40’22.9”	102º06’28.4”	2 127	Toritos
ZAC	Zacatecas	22º45’26.9”	102º33’51.1”	2 418	Aceitilla, girasol, toloache
ZAC	Zacatecas	22º45’51.4”	102º38’21.2”	2 325	Sangre de grado
ZAC	Zacatecas	22º46’00.3”	102º35’03.8”	2 444	Chicalote
ZAC	Guadalupe	22º45’04.2”	102º27’10.4”	2 193	Calabacilla loca
ZAC	Loreto	22º16’19.3”	101º57’30.4”	2 047	Pirul
ZAC	Guadalupe	22º40’53.5”	102º33’27.1”	2 376	Mezquite

To estimate its productivity in the field, once the plant was located, the methodology proposed by Mostacedo and Fredericksen (2000) was followed, which recommends the sampling method by square plot of 1 m $*$ 1 m for herbaceous plants, of 5 m $*$ 5 m for creepers and 10 m $*$ 10 m for shrubs and trees. In each of the plots, the coverage, density and frequency of plants, as well as the number of seeds per plant, of all the plants contained in the respective plot were estimated. The variables density and number of seeds per plant were used to estimate the potential yield of seed extrapolated to one hectare under natural conditions. For each collection site, the location and altitude coordinates were recorded using a GPS and georeferencing was performed using the Google Maps program.

Morphological characterization of seeds

The clean seeds were dried at 60 °C for a period of 18 h. Subsequently, the weight (g) of 100 seeds taken at random from each of the species considered in the study was recorded by means of an analytical balance (Vlab V300®). To 10 seeds of each the species were measured length, width and thickness (cm) using a vernier and a tape measure, according to the methodology proposed by Pérez *et al*. (2006).

Extraction and characterization of oils

The chemical extraction of oil was carried out using a fat and oil determinant (Soxtec System HT 1043), according to the technique applied by Loredo (2012). All analyzes were performed in triplicate.

Once the oils were extracted, the determination of the following parameters was carried out, taking into consideration the Official Mexican Standards (NOM): refractive index (NMX-F-074-S 1981), saponification index (NMX-F-174-S-1981), acid number (NMX-F-101-1987), iodine number (NMX-F-408-S-1981) and peroxide index (NMX-F-154-1987). In this study, considering that each species produced a different oil content, and that in its analysis different sample quantities are required, the characterization was done in duplicate, depending on the amount of oil available from each species and was concentrated in the chemical aspect.

Infrared spectra of the samples extracted in the region 600 to 4 000 cm^{-1} were also made in a Nicolet is50® spectrophotometer by comparing the absorbance peaks of the signals obtained through the analysis of the functional groups present in each one of the oil samples. For this, oleic, linoleic, linolenic and palmitic fatty acid (Sigma-Aldrich®) standards were used. The graphics were made through the Origin Pro 8 Program.

Statistic analysis

The variables obtained were calculated descriptive statistics parameters (means and standard deviation) and for potential seed and oil yield, analysis of variance was performed; the separation of means was performed by the Tukey test ($p\leq 0.05$) using the SAS program (Statiscal Analysis Software, V9.1). In addition, some principal components analysis (PCA) was carried out using the InfoStat/L program.

Results and discussion

Potential seed and oil yield

The statistical analysis performed shows that there is a statistical difference for the potential seed yield and oil yield, depending on the vegetable species under study ($p\leq 0.05$). *Agave* sp., was superior and statistically different (DSH= 2457) to the rest of the species, registering a potential seed yield of 24 305 kg ha^{-1}. However, this represents a special case given that in large species of this type of plants maturation can occur between 10 and 25 years, while in small plants of this species can occur between four and five years (García-Mendoza, 2002).

In the Figure 1 shows that four species registered potential seed yields greater than 1 000 kg ha^{-1}, but excel, in addition to *Agave* sp., *A. mexicana*, *P. louisianica* and *D. inoxia*. On the other hand, seven species presented seed yield values lower than 100 kg ha^{-1}, with *L. tridentata* standing out among them with only 0.8 kg ha^{-1} despite having registered one of the highest densities. An important group of species were located with potential intermediate seed yields, with the exception of *P. glandulosa*, all of them are medium-low, herbaceous and creeping. Regarding *B. odorata*, it highlights that despite registering a high density per unit area and having a high number of seeds, it was not reflected in their potential yield due to their low weight. Similar behavior was observed with *L. tridentata* since its seeds are very light.

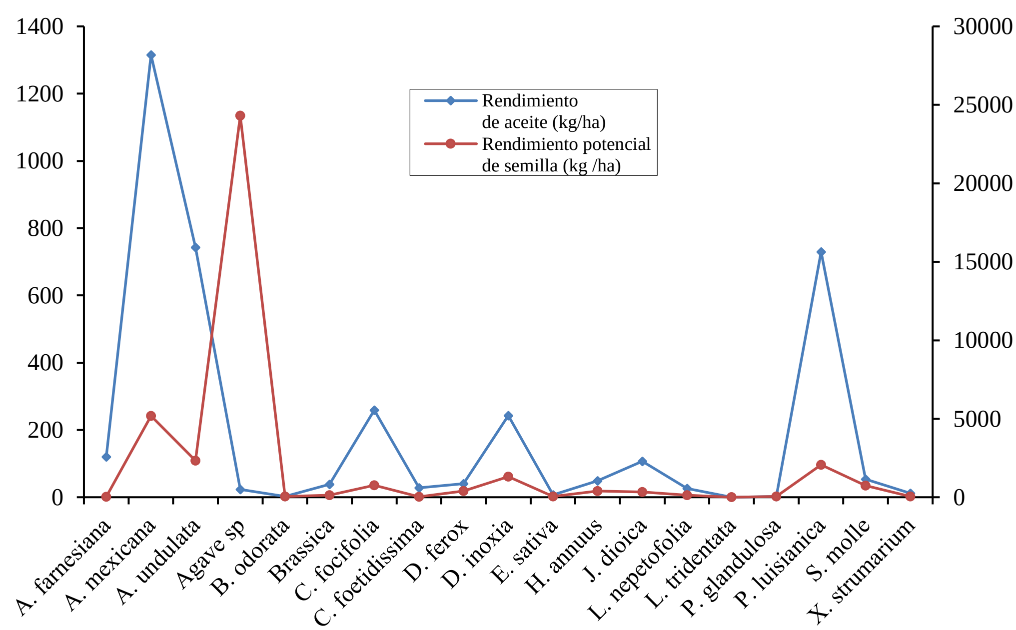

Figure 1. Relationship between potential seed yield and oil content.

In *X. strumarium* its reduced yield could be associated with the presence of a low number of seeds (two seeds per fruit); however, it is a species to consider since its seed contains 20.4% oil. In the particular case of *Brassica* sp., its low yield could be the result of its low density and small seed size; however, it has a high percentage of oil (30.3%), which is interesting especially if one considers that it can be cultivated intensively in order to increase its seed yield.

In other cultivated oleaginous species, very contrasting results have been observed in terms of yields, especially considering that many of them are under experimental conditions. Mazzani (2007) points out that *R. communis* can produce between 350 and 700 kg ha^{-1} when minimal care is provided and up to 1 250 kg ha^{-1} in already technified sowings. In Cuba, when evaluating different accessions of the same species, yields of up to 4 398 kg ha^{-1} were obtained (Machado *et al*., 2012).

The results obtained for oil yield of the species studied are shown in Figure 1. *A. mexicana* was the species with the highest oil yield with 1 315 kg ha^{-1}, statistically different from the rest of the species (DSH= 773.2). *A. mexicana* was as competitive or better than some cash crops currently used in the production of biodiesel, such as soy *Glycine max* (335 kg ha^{-1}), sunflower *Helianthus annuus* (568 kg ha^{-1}), peanut *Arachis hypogaea* (712 kg ha^{-1}), rape *Brassica napus* (832 kg ha^{-1}), pinion *Jatropha curcas* (950 kg ha^{-1}), castor oil *Ricinus communis* (1 133 kg ha^{-1}), tung *Aleurites fordii* (1 204 kg ha^{-1}), according to Martinez-Valencia *et al*. (2011). *A. undulata* and *P. lousianica* showed interesting oil yields of 743 and 730 kg ha^{-1}.

These are derived from its large number of fruits, size and quantity seeds and especially its oil contents greater than 30%. However, their values are lower at 5 772 L ha^{-1} obtained in sunflower by INTA (1997), but close to those consigned by Rebora and Gomez (2007) for rapeseed, where in managed varieties 1 466 L ha^{-1} were obtained. For its part, *A. mexicana* registered a potential oil yield of 1 315.9 kg ha^{-1}, a value much higher than that found by Singh (2010) of 190 L ha^{-1}, so it can be considered that, with proper management and high densities of plants, yields could increase. It is worth noting that this oil yield is even higher than that obtained in *R. communis* in Cuba (1 130.2 kg ha^{-1}) (Machado *et al*., 2012).

In Figure 1 highlights the trend presented in *C. ficifolia* as it presents a combination of high seed yield and high oil content. On the contrary, the contrasts of the *A. undulata* species are observed to obtain a high content of oil combined with a low yield of seeds and the particular case of *S. molle* to generate a large number of seeds, but with a small percentage of oil.

Percentage of oil

In Figure 2, the percentages of oil obtained from the seeds of the species used are presented. It is highlighted that six species presented percentages higher than 30%, among which are: *C. ficifolia* (34.1), *C. foetidissima* (33.90), *P. louisanica* (33.6), *A. undulata* (31.40), *J. diodica* (32.86) and *Brassica* sp. (30.33). These values are generally lower than those reported by Martinez-Valencia *et al*. (2011) for oilseeds commercially cultivated as sunflower *Helianthus annuus* (45-55%), canola *Brassica napa* (40-44%), palm *Elaeis guineensis* (44-57%), coconut *Cocus nucifera* (65-75%), peanut *Arachis hypogaea* (48-50%) and safflower *Carthamus tinctorius* (35-40%); or the one reported by Calderón *et al*. (2013) of 51% for palm. The highest yields, on the other hand, are within the values observed by Cruz *et al*. (2015) for various accessions of *Jatropha curcas*, which ranged between 31 and 49%, as well as those mentioned by Martínez-Valencia *et al*. (2011) for this same plant ranging from 20 to 60% and for *Ricinus communis* (26-66%). However, they are superior to yields soybean *Glycine max* (18-20%) and cotton *Gossypium hirsutum* (18-25%), as reported by Martínez-Valencia *et al*. (2011). In Figure 2, it is also seen that five of the species used obtained an oil percentage between 10 and 30% and six resulted with an oil percentage lower than 10%.

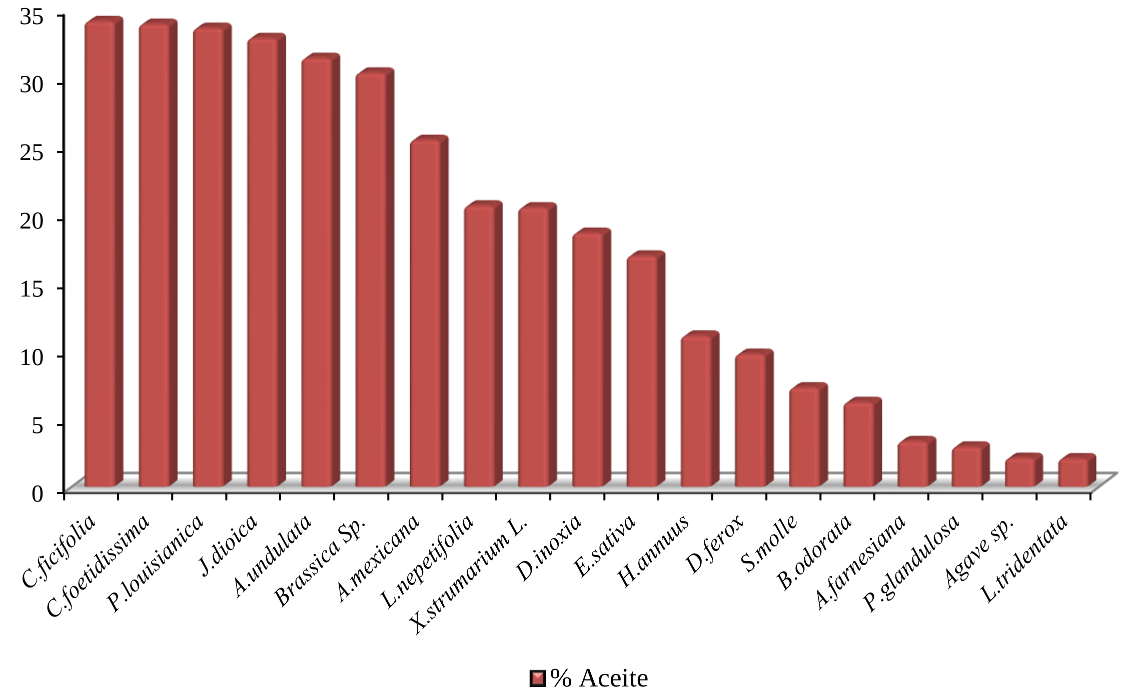

Figure 2. Percentage of oil obtained from the species of plants collected.

Figure 3, elaborated with the first two main components, shows that the field variables that influence the percentage and content of oil are the density of plants and the weight of 100 seeds (g), since species such as: *A. mexicana*, *D. inoxia*, *A. undulata*, *P. louisianica*, *C. ficifolia* and *C. foetidissima*, are grouped, indicating a similar behavior of these species. In the case of higher species such as *S. molle*, *A. farnesiana*, *L. tridentata* and *P. glandulosa* are associated with a low frequency and a low oil content. Likewise, the tendency was observed that the plant height variable is negatively related to the oil content, since none of the tree species presented a high percentage of oil. Although it is also observed that the plant height variable shows a tendency to produce a higher potential seed yield. As for the components, the first two explains a total of 49% of the variability contained in the data.

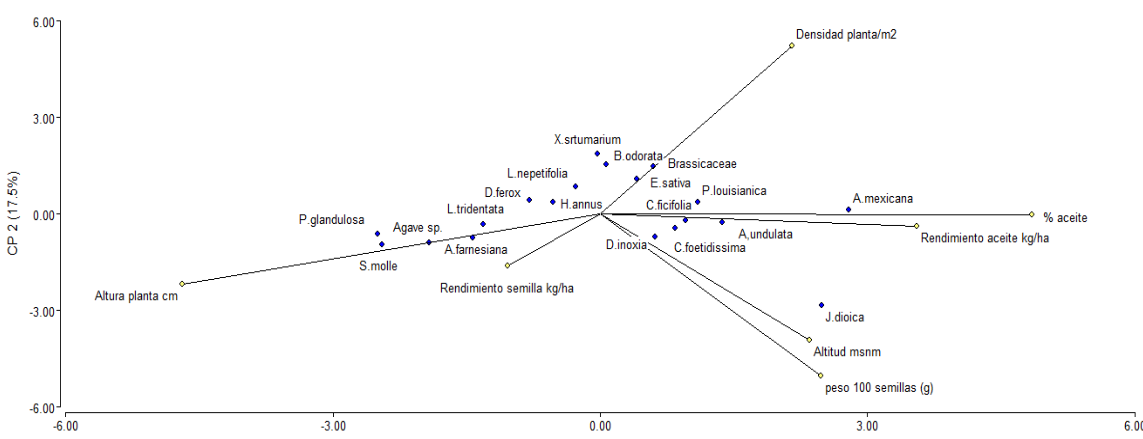

Figure 3. Behavior of 19 plant species and main variables with the main components 1 and 2.

Physical-chemical characterization of oils

The quality and efficiency of biodiesel depend on the process and the quality of the oil generated by the crop; that is, oils with a low concentration of free fatty acids, high in monounsaturated fatty acids and without gums and impurities, among other physicochemical properties (Martínez-Valencia *et al*., 2011). Martínez-Sánchez *et al*. (2015) point out that the most used chemical characteristics for the classification and determination of the commercial quality of the oils are: iodine index, saponification, peroxides and acidity, within the physical characteristics they emphasize the specific gravity, the refractive index, density and the melting point. The values of the indices of refraction, saponification, iodine, acidity and peroxides, of the oils contained in the species studied, are shown in Table 2.

Table 2. Physico-chemical characteristics of vegetable oils.

Species	IR	IS (mg KOH g^{-1})	IY (g I_2 100 g^{-1})	IA (% oleic acid)	IP (meq kg^{-1})
A. farnesiana	1.4768		60.68		
A. mexicana	1.4730	119.31	117.94	11.71	0.39
A. undulata	1.4870	141.48	123.8	11.25	0.75
Agave sp.	1.4762				0.68
B. odorata	1.4725	149.81	96.57		1.62
Brassica sp.	1.4715	174.17	29.45	3.13	0.79
C. ficifolia	1.4748		73.12	0.68	1.08
C. foetidissima	1.4750	180.02	141.26	11.51	0.47
D. ferox	1.4700	142.31		29.66	
D. inoxia	1.4720	146.22	114.95	8.7	1.06
E. sativa	1.4780	129.64	97.59	4.24	
H. annuus	1.4723	152.27	29.68	7.69	0.77
J. dioica	1.4725		113.49		
L. nepetifolia	1.4658	149.93	30.95	36.17	0.47
P. glandulosa	1.4757				
P. louisianica	1.4735	182.83	116.65	3.5	0.72
S. molle	1.485		99.4	26.8	0.79
X. strumarium	1.4750		23.35	1.79	0.67

IR= Refractive index; IS= index of saponification; IY= index of iodine; IA= index of acidity; IP= index of peroxides.

The refractive index (IR) of the oils registered very homogeneous values, ranging from 1 473-1 487. The oil of *R. communis*, one of the most used oils in the production of biodiesel, has a value of 1.47 or very close (ASTM, 2008). Some of the outstanding species that showed this characteristic were *Datura ferox* (1.47), *Datura inoxia* (1.472), *A. mexicana* (1.473) and *C. foetidissima* (1.475).

The saponification indexes (IS) registered in the oils of *C. foetidissima*, *P. louisianica* and *Brassica* sp., Are very similar to the values obtained for *R. communis* (174.6, 176.3 and 173.8 mg KOH g^{-1}) indicated by Danlami *et al*. (2015), the oils of these species could be used in the production of biodiesel. It is worth noting that some of the oils obtained from the plants studied share characteristics with the sunflower, rapeseed and castor oil mentioned by CORPODIB (2003). Also, in the cosmetics industry, Ruiz and Huesa (1991) observed IS values for Shea Butter (*Butyruspermum parki*) 180-190 mg KOH g^{-1}, these values are similar with *C. foetidissima* oils (180.02 mg KOH g^{-1}) and *P. louisianica* (182.83 mg KOH g^{-1}), which makes possible its potential use in the cosmetics industry.

Cruz *et al*. (2015) obtained in *J. curcas*, one of the inputs most used in obtaining biodiesel, IS that ranged between 192 and 196 mg KOH g^{-1}, only *P. louisianica* approached these values.

In relation to the acidity index (AI), Martínez-Valencia *et al*. (2011) mention that values greater than 5% indicate that the oil contains a high amount of free fatty acids, generated by a high degree of hydrolysis, which negatively affects the efficiency of transesterification in the biodiesel production process. In Table 2, it can be seen that the oil of the species with AI of less than 5% are *Cucurbita ficifolia* (0.68%), *Brassica* sp. (3.13%), *Eruca sativa* (4.24%), *Proboscidea louisianica* (3.50%) and *Xanthium strumarium* (1.79%), which makes them suitable for the production of biodiesel without the need to carry out a pretreatment of the oil to neutralize the acids free fatty acids. The oil of the rest of the species presents AI greater than 5%, of which *Datura ferox*, *Leonotis nepetifolia* and *Schinus molle* had the highest values with 29.66, 36.17 and 26.80%, respectively.

Other oils used to make biodiesel such as soybean show an AI of 1.5% (Pinzi *et al*., 2009), while those of oil palm (*Elaeis guineensis*), Mexican pinion (*Jatropha curcas*) and castor bean (*Ricinus communis*) present values for this index of 4.95, 3.19 and 1.77%, respectively (Martínez-Valencia *et al*., 2011). On the other hand, Lafargue-Pérez *et al*. (2012) report values of 11.84% for *J. curcas*.

The iodine index (IY) of the oil in the species studied showed a strong oscillation between 23.35 and 141.26 g I_2 100 g^{-1} (Table 2). High values of IY indicate high degrees of unsaturation in the fatty acids of triglycerides, which causes, in the biodiesel made from them, a greater tendency to oxidize and low cetane numbers, which in turn results in a biodiesel unstable and of low combustion quality in diesel engines (Martinez-Valencia *et al*., 2011). For that reason, the European standard EN-14214 establishes an upper limit for the IY of 120 g I_2 100 g^{-1}. In that sense, the oils of *A. undulata* and *C. foetidissima*, with 123.8 and 141.26 g I_2 100 g^{-1}, respectively, could produce a biodiesel that does not conform to the norm. However, oils with high IY can be used in the manufacture of cosmetics for the ease with which they are absorbed by the skin (Londoño *et al*., 2011) or in the production of high quality food oils.

On the other hand, low values of IY indicate a greater presence of saturated fatty acids and a lower presence of polyunsaturates, which provides greater stability as they are less prone to oxidation and with higher cetane numbers; however, these saturated fatty acids tend to solidify at higher temperatures, so their use for biodiesel should be restricted to tropical regions, since in regions with cold climates, diesel engines may present starting problems (Martínez-Valencia *et al*., 2011). The most desirable in the IY, is that they present low values, since this allows a greater stability of the oil in storage (Martínez-Sánchez *et al*., 2015).

Oils with low values can also be used in personal hygiene products. The IY registered for oil from the African palm *Elaeis guineensis* is 52.29 g I_2 100 g^{-1} (Calderón *et al*., 2013) and from 53 to 57 g I_2 100 g^{-1} (Martínez-Valencia *et al*., 2011).

However, according to Gunstone *et al*. (2004) about 82% of the oil *E*. *guineensis* are saturated fatty acids, so it tends to solidify at low temperatures, which is why it is recommended to use biodiesel made from it only in hot climates. It could be inferred that the oils of *Brassica* sp., *H*. *annuus*, *L*. *nepetifolia* and *X*. *strumarium*, with IY of 29, 29, 31 and 23 g I_2 100 g^{-1}, could produce a biodiesel with this problem. These same authors indicate values of 121-143, 96-117, 127-142, 96-101 and 85 g I_2 100 g^{-1}, for soy, rapeseed, sunflower, mexican pinion and castor bean crops, respectively. On the other hand, Armendariz *et al*. (2015) mention, for biodiesel produced from *R*. *communis*, an IY of 85 g I_2 100 g^{-1}, values similar to those of *B*. *odorata*, *C*. *ficifolia*, *E*. *sativa* and *S*. *molle*.

The iodine (IY) levels obtained in the oils of the species studied, due to their degree of unsaturation, can be considered as drying, semi-drying and non-drying. Driers, usually, are those that have a high IY (Bailey, 1984) and can be used in the production of paints and varnishes. For this purpose the oils of the species *C. foetidissima*, *J. dioica*, *D. inoxia*, and *P. louisianica* could be used since they have IY of 141.26, 113.49, 114.95 and 116.65 g I_2 100 g^{-1}, respectively. The non-drying oils include *A. farnesiana*, *B. odorata*, *Brassica* sp., C. *ficifolia*, *E. sativa*, *H. annuus*, *L. nepetifolia*, *S. molle* and *X. strumarium*. These oils by their characteristics under normal weather conditions do not solidify. Semi-dryers can be considered *A. undulata*, *A. mexicana*, *D. inoxia*, *J. dioica* and *P. louisianica*, with characteristics similar to commercial oils such as sesame and corn (Ortega and Vázquez, 1993).

Peroxides are known as compounds of the primary decomposition of the oxidation of fats and oils (Gómez, 2010), so that those values of peroxide index (IP) close to 0 meq kg^{-1}, are related to a level of low rancidity; that is to say, they oxidize slowly allowing the oil to retain its quality for a longer time, giving them an advantage for possible later use. A high IP value indicates the presence of oxidation; in this study the oils of the majority of the vegetable species studied had an IP less than 1. According to Luna-Guevara and Guerrero-Beltrán (2012) the IP and the AI are considered indicators of quality and freshness of the oils. For African palm oil, very high peroxide values of 31.3 meq kg^{-1} were obtained (Calderón *et al*., 2013).

FTIR spectrometry

Figure 4 shows the spectrum of palmitic, oleic, linoleic and linolenic fatty acid standards, determined. In this way, the purity pattern of the standards was confirmed and allowed to compare them with the oil samples of the species studied. It is observed, for example, that the palmitic one expresses in the fingerprint seven peaks located in the region 1 187-1 319 cm^{-1} that differentiate it from the other fatty acids which did not present those characteristic peaks.

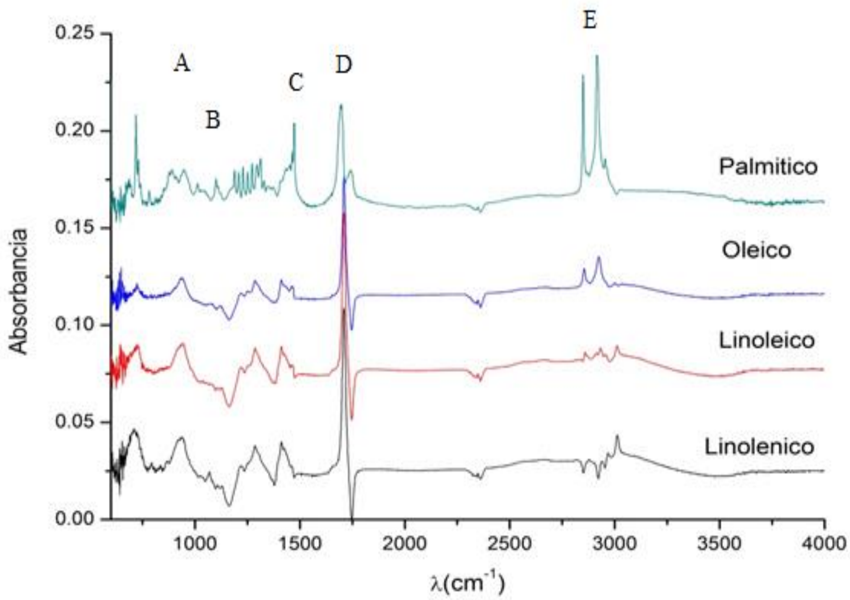

Figure 4. Infrared spectrum of fatty acids used as a standard.

According to the spectrum of fatty acids and by comparison, the fatty acids present in each of the species studied were detected. Table 3 shows a predominance of oleic and palmitic acids in most species. In the case of *C. foetidissima*, *A. undulata* and *J. dioica*, linoleic and linolenic acids were recorded, which are important in the diet since the body does not synthesize them, which gives them a greater added value for possible use as edible oils (Koolman and Röhm, 2004).

Table 3. Main fatty acids present in the oils of the species studied.

Species	Oleic	Linoleic	Linolenic	Palmitic
Acacia farnesiana			X	
Argemone mexicana	X			
Apodanthera undulata			X	
Agave sp.				X
Bidens odorata	X			
Brassica sp.				X
Cucurbita ficifolia	X			
Cucurbita foetidissima	X	X	X	
Datura ferox				X
Datura inoxia				
Eruca sativa	X			X
Helianthus annuus	X			X
Jatropha dioica		X		
Leonotis nepetifolia	X			
Larrea tridentata				X
Prosopis glandulosa	X			
Proboscidea louisianica				X
Xanthium strumarium				X

It is worth mentioning that oleic fatty acid (monounsaturated), besides being one of the main components of the main edible oils, can contribute to reduce the levels of glucose and cholesterol in the blood, as well as reduce the risk of cardiovascular diseases and obesity (Luna-Guevara and Guerrero-Beltrán, 2012).

Conclusions

The wild species studied presented interesting agroproductive characteristics in terms of seed productivity and oil content.

Six species (*C. ficifolia*, *C. foetidissima*, *A. undulata*, *J. dioica*, *P. louisianica* and *Brasica* sp.) Obtained percentages higher than 30%, which is why they are considered of interest in oil production.

Considering the physical and chemical characteristics of the oils, its potential use is suggested not only in the biofuels industry, but also its possible use in the food, pharmaceutical and cosmetological industries, as well as in the obtaining of higher added value products.

The oleic and palmitic fatty acids are those that are present in the majority of the oils of the species studied. *C. foetidissima*, *A. undulata* and *J. dioica* presented edible linoleic and linolenic acids with high antioxidant, functional and nutraceutical potential.

It is recommended to carry out a proximal analysis in order to consider the residual paste for the elaboration or complementation of some food or forage products, or in the obtaining of bioactive products.

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Cited literature

Agüero-Rodríguez, J. C.; Tepetla-Montes, J. y Torres-Beristaín, B. 2015. Producción de biocombustibles a partir de la caña en Veracruz, México: perspectivas y riesgos socio-ambientales. Ciencia UAT. 9(2):74-84.

American Society for Testing Materials. (ASTM). 2008. http://www.astm.org/database.cart/historical/d6751-08.htm.

Armendáriz, J.; La Puerta, M.; Zavala, F.; García-Zambrano, E. and Del Carmen, M. 2015. Evaluation of eleven genotypes of castor oil plant (*Ricinus communis* L.). Industrial Crops and Products. 77(23):484-490.

Bailey, E. 1984. Aceites y grasas industriales. Editorial Reverté, SA. España. 740 p.

Calderón, A. A. I. A.; Monterrosas, S. M.; Arroyo, T. J. R.; Chávez, B. E.; Villegas, R. M. L. O. y Carranza, T. V. 2013. Obtención y caracterización de biodiesel a partir de aceite crudo de la palma africana *Elaeis guineensis*. Ing. Rev. Académica de la FI-UADY. 17(2):103-109.

CORPODIB. 2003. Corporación para el Desarrollo Industrial de la Biotecnología y Producción Limpia-Programa estratégico para la producción de biodiesel, combustible vegetal a partir de aceites vegetales: evaluación de las variedades más promisorias para la producción de aceite vegetal y su potencial implementación en Colombia. http://www.si3ea.gov.co/si3ea/documentos/documentacion/biodiesel/capitulo%202.pdf.

Cruz, R. B. A.; Pérez-Vázquez, A.; García, P. E.; Gallardo, L. F. y Marcos, S. R. 2015. Análisis químico morfológico comparativo de accesiones de *Jatropha curcas* L. del estado de Veracruz. Rev. Mex. Cienc. Agríc. 6(3):589-601.

Danlami, J.; Arsad, A and Zaini, M. 2015. Characterization and process optimization of castor oil (*Ricinus communis* L.) extracted by the soxhlet method using polar and non-polar solvents. J. Taiwan Inst. Chem. Eng. 47:99-104.

Estrada, C. e Islas. J. 2010. Energías alternas: propuesta de investigación y desarrollo tecnológico para México. Academia Mexicana de Ciencias. 1ra. Ed. México. 136 p.

García-Mendoza, A. 2002. Distribution of the genus *Agave* (Agavaceae) and its endemic species in México. Cactus Succulent J. 74:177-187.

Gómez, E. 2010. Índice de peróxido. Informe núm. 4. Universidad Agraria de la Selva, Perú. http://documents.mx/documents/informe-n04-indice-de-peroxido.html.

Gunstone, F. D.; Harwood, J. L. and Padley, F. B. 2004. The lipid handbook. Second edition. London. Chapman & Hall. 286 p.

INTA. 1997. Instituto Nacional de Tecnología Agropecuaria- Secretaría de Agricultura, Ganadería, Pesca y Alimentación-Ministerio de Economía y Obras y Servicios Públicos. http://inta.gob.ar/sites/default/files/script-tmp-uia_practica_para_el_cultivo_de_girasol.pdf.

Koolman, J and Röhm, K. H. 2004. Bioquímica, Texto y Atlas. 3ª Ed. Editorial Médica Panamericana. 488 p. ISBN 84-7903-724-5.

Lafargue-Pérez, F.; Barrera-Vaillant, N.; Assuncao-Nascimento, J.; Diaz-Vazquez, M. y Rodríguez-Martínez, C. 2012. Caracterización fisicoquímica del aceite vegetal de *Jatropha curcas* L. Tecnología Química. 32(2):162-165.

Londoño, P.; Mires-Pitre, A. y Hernández, E. C. 2011. Extracción y caracterización del aceite crudo de la almendra de durazno *Prunus persica*. Avances en Ciencia e Ingeniería. 3(4):37-46.

Loredo, S. 2012. Perfil de ácidos grasos en *Lupines uncinatus* S. Tesis doctoral, especialista en edafología. Colegio de Postgraduados, *Campus* Montecillo. 155 p.

Luna-Guevara, J. J. y Guerrero-Beltrán, J. A. 2012. Evaluación de algunos índices físicos y químicos de aceites extraídos de nuez pecanera, nuez de castilla y macadamia. Ciencia y Tecnología de Alimentos. 22(2):33-39.

Machado, R.; Suárez, J. y Alfonso, M. 2012. Caracterización morfológica y agroproductiva de procedencias de *Ricinus communnis* L. para la producción de aceite. Pastos y Forrajes. 35(4):381-392.

Martínez-Sánchez, J.; Espinosa-Paz, N.; Fernández-González, I.; Martínez-Valencia, B. B.; De la Cruz-Morales, F. R. y Cadena-Iñiguez, P. 2015. Evaluación fisicoquímica del aceite de variedades criollas de *Arachis hypogaea* L. Revista Agroproductividad. 8(8):12-18.

Martínez-Valencia, B. B.; Zamarripa-Colmenero, A.; Solís-Bonilla, J. L. y López-Ángel, L. J. México 2011. Calidad fisicoquímica de insumos bioenergéticos para la producción de biodiesel en México. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Rosario Izapa, Tuxtla Chico, Chiapas. México. Folleto técnico núm. 24. 63 p.

Mazzani, E. 2007. El tártago: la planta, su importancia y usos. CENIAP Hoy. núm. 14. http://www.cadenahortofrutic ola.org/admin/bibli/576tartago_importancia_usos.pdf.

Montiel-Montoya, J. 2010. Potencial y riesgo ambiental de los bioenergéticos en México. Ra Ximhai, Revista de Sociedad, Cultura y Desarrollo Sustentable. 6(1):57-62.

Mostacedo, B. y Fredericksen, T. 2000 Manual de métodos básicos de muestreo en ecología aplicada, Santa Cruz, Bolivia. BolFor. 88 p.

NMX-F-074-S-1981. Norma Oficial Mexicana. Determinación del índice de refracción.

NMX-F-101-1987. Norma Oficial Mexicana. Determinación del índice de acidez.

NMX-F-154-1987. Norma Oficial Mexicana. Determinación del índice de peróxidos.

NMX-F-174-S-1981. Norma Oficial Mexicana. Determinación del índice de saponificación.

NMX-F-408-S-1981. Norma Oficial Mexicana. Determinación del índice de yodo por el método de análisis de Hanus.

Ortega, M. y Vázquez, L. 1993. Caracterización fisicoquímica del aceite crudo y refinado de la semilla de *Proboscidea parviflora* (uña de gato). Grasas y Aceites. 44(1):30-34.

Pérez, C.; Hernández, L.; Valerio, F.; García, G.; Caraballo, A.; Vázquez, T. y Tovar, M. 2006. Tamaño de semilla y relación con su calidad fisiológica en variedades de maíz para forraje. Agric. Téc. Méx. 32(3):341-352.

Pinzi, S.; García, L.; López, J. J.; de Castro, L. M. D.; Dorado, P. G. and Dorado, M. 2009. The ideal vegetable oil-based biodiesel composition: a review of social, economical and technical implications. Energy & Fuels. 23(5):2325-2341.

Rebora, C. y Gómez, A. 2007. Rendimiento de aceite de colza cultivada bajo riego. FCA Uncayo. 39(2):101-108.

Reveles, S. F. O.; Rosales, S. R.; Nava, B. C. A.; Delgado L., E.; Cuéllar R., E. I.; Carrete C., F. O. y Ríos, S. J. C. 2010. Identificación de especies vegetales con potencial para la producción de biocombustibles líquidos en Durango, México. Rev. Mex. Cienc. Agríc. 1(1):45-54.

Reyes-Reyes, A. L.; Zamarripa-Colmenero, A.; Iracheta-Donjuan, L.; Espinosa-Zaragoza, S. y Won-Villarreal, A. 2015. Perspectivas de la producción de biodiesel proveniente de materia prima renovable. Agroproductividad. 8(4):19-23.

Rodríguez, H. R. y Zamarripa, C. A. 2013. Competitividad de la higuerilla (*Ricinus communis*) para biocombustible en relación a los cultivos actuales en el edo. de Oaxaca, México. Rev. Mex. Agron. 17(32):306-318.

Romero, P. A.; Hernández, J. M.; León, M. A. y Sangermán-Jarquín, D. M. 2015. Impacto en el mercado mexicano de maíz en ausencia de políticas de producción de biocombustibles en Estados Unidos de América. Rev. Mex. Cienc. Agríc. 6(5):1023-1033.

Ruiz, M. y Huesa, J. 1991 La manteca de Karité. Grasas y Aceites. 42(2):151-154.

Singh, D. 2010. Low cost production of ester from non-edible oil of *Argemone Mexicana*. Bio. Bioenergy. 34(4):545-549.

Statistical Analysis Software. (SAS). SAS Institute Inc. Cary, NC. 2011.

Wilches, F. A. M. 2011. Biocombustibles: ¿son realmente amigables con el medio ambiente? Rev. Colomb. Bioética. 6(1):89-102.