Article

Variability in oil content in Argentine jojoba

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Abstract

Jojoba is a perennial, shrubby species, native to the Sonoran Desert, in the USA and Mexico. Jojoba was introduced in Argentina in 1976 in the province of Cordoba. Argentina is the main producer of jojoba in the world, followed by Israel, Peru and the USA. Until now, the vast majority of selection efforts have been essentially based on seed yields. The objective of this work is to determine the importance of including in the selection programs, the variability in the oil content existing in the species. The present study carried out with the available information and the one generated here, demonstrates the significant significant variability ($p< 0.05$) in quantity and composition of fatty acids. Knowing and raising the oil content and even its chemical composition, could allow the formation of standards that empower the producer to access bonuses for content and quality.

Keywords: Argentina, genetics, jojoba, oil.

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Introduction

Jojoba (*Simmondsia chinensis* Link. [Schneider]) is a perennial, shrubby species, native to the Sonoran Desert located in parts of the states of Arizona and California, in the southwestern United States, and those of Baja California, Baja Southern California and Sonora in northwestern Mexico. Its seed has a wax that is liquid at room temperature, which is why it is generally called oil, and it is widely used in high-quality cosmetology and lubrication of precision instruments (Ayerza, 1990a).

Also, its content of the compound Simmondsina opens up new and promising opportunities for the species as an appetite inhibitor (Kolodziejczyk *et al*., 2000). Jojoba was introduced in Argentina in 1976 in the town of Chancani, Cordoba province (Ayerza, 1980). The introduced genetics was the origin of several clones implanted in plantations existing today in the country. It was first cloned in Argentina in 1986 and from there it was dispersed in commercial plantations established in the towns of Catinzaco, La Rioja province, and Zancas and Pomancillo in the province of Catamarca. From these three places, several clones and seeds became part of plantations in the Aimogasta-Bañado de los Pantanos region, which grew on the surface with the cloning and multiplication of plants of this origin, continuing this process even today. Chancani introduced seeds from wild plants from the Tucson Mountains and southern California.

The first comparative tests showed a superior behavior of the plants originated in Arizona, so those of California were left aside and all subsequent multiplications only used the first ones (Ayerza and Zeaser, 1987). The first plantation carried out in Bañado de los Pantanos, La Rioja, in 1982, with seeds of plants from southern California (Ayerza, 1984), was an important source of obtaining a genetic bank. Seeds and rooted cuttings of plants cloned there were subsequently distributed, but information on their origin was not maintained. Of these materials, superior specimens were selected in the new plantations, which were later cloned and used to increase these ventures. This origin is probably the most widespread today in Aimogasta-Bañado de los Pantanos. Figure 1 summarizes the history of the origin and path traveled by the germplasm introduced into the country.

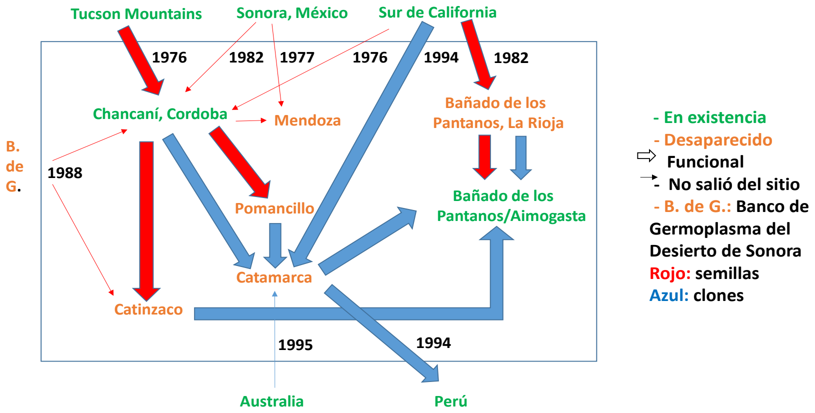

Figure 1. Origin of the jojoba genotypes introduced in Argentina.

Argentina is the main producer of jojoba in the world, followed by Israel, Peru and the USA (Ayerza, 2016). Although today the surface of jojoba in production in the country is 2 470 ha (Ayerza, 2018a), the implanted area reached 13 000 ha in 2007 (Coates and Ayerza, 2008), but the plantations of thousands of hectares located In the center and north of the Chaco Seco ecosystem, they were abandoned when it was determined that there the jojoba could not fulfill its requirement of vernalization (Ayerza, 1992).

Until now, the vast majority of related efforts in clonal variety selection have essentially been based on seed yields, with virtually no regard to oil content. The objective of this work is to show the variation that oil presents and the importance of incorporating it in the selection plans of farmers in the region. For this purpose, a review of the available information on the oil content in Argentine jojoba is presented.

The review compares the oil content of the native material of the Sonora Desert present in the collection made by the author in 1986 and financed by the Encyclopaedia Britannica, with that of the one introduced in Argentina (Ayerza, 1990b) and also the variations that showed various genotypes in different ecosystems during the existence of the crop in the country. Recently, The National Academies of Sciences, Engineering, and Medicine of the USA (2018), it is emphasized that among the most important activities that science must carry out for agriculture to meet the needs of food and industries in 2030, is the formation of important gene banks for the development of new varieties. Due to the great clearing of the Sonora Desert.

There is an urgent need to collect the genetic diversity of jojoba before it is irretrievably lost, and with it the possibility of obtaining genotypes that provide resistance to future pests, diseases and climatic changes and allow increased yields of its different components and even the survival of the species. The objective of this work is to demonstrate the importance of including the variability in the oil content existing in the species in the selection programs.

Materials and methods

The information used comes from the extraction of oil-related data from work carried out and published by the author. Having the original data, in most cases new statistical analyzes (standard deviations, correlations and regressions) were added to what was published, for which the Cohort Stat program (2006) and data not included in said works such as climatological and geographic information and their interactions.

This allowed determining additional results to those originally published and thus broadening the discussions and conclusions. At the national level. The descriptions of the materials and methods of each one of the plots and of the chemical analyzes carried out in determining the oil content and composition of fatty acids are in each of the original works cited.

Results and discussion

In the Table 1 (Ayerza, 1990a) shows the geographical and climatic characteristics of the areas of the native jojoba populations collected through their natural dispersal area. The statistical correlation analysis of the data in this table shows a high and positive significant correlation (R= 0.56; $p< 0.0102^{*}$) between terrain altitude and rainfall (Figure 2) and significant (R= -0.727; $p< 0.0003^{***}$) very high and negative between altitude and mean annual temperature (Figure 3). No significant relationship was found between any of the topographic or climatic data and the percentage of oil or seed weight, nor between these last two variables.

The oil contents in the seeds of this collection showed significant differences ($p< 0.05\%$) between them (Table 1). Seeds collected at Cave Creek, Arizona had the significantly ($p< 0.05$) highest oil content (53%), followed by those from Tonto National Forest, Arizona (51.8%).

Table 1. Oil content and seed weight of native plants of the Sonoran Desert and geographic and climatic characteristics of the sampled sites.

Site	Latitude North	Longitude West	Oil (%)[7]	Seed weight (g)	Height (m)[8]	Rain (mm)[9]	Temperature[10] (°C)
Aguanga[1]	33° 26’ 50”	116° 52’ 54”	50.2 ^{de}[11]	0.5^{mn}[11]	628	400	14
Jacumba[1]	32° 39’ 90”	116° 13’ 11”	47.3 ^{h}	0.38 ^{p}	859	402	14.6
Joshua Tree[1]	34° 04’ 10”	116° 10’ 34”	48 ^{fgh}	0.61 ^{f}	858	130	15.8
La Huerta[2]	31° 54’ 12”	116° 15’ 39”	46 ^{i}	0.55 ^{ij}	600	180	16.1
San Matis[2]	31° 19’ 14”	116° 15’ 51”	48 ^{f}	0.36 ^{q}	968	215	16.6
Ensenada[2]	31° 51’ 10”	116° 37’ 27”	48.4 ^{fg}	0.43 ^{o}	18	277	16.4
El Palmar[3]	23° 16’ 18”	110° 10’ 39”	50 ^{e}	0.56 ^{hij}	1	195	24.6
El Gaspareño[3]	23° 15’ 19”	110° 10’ 34”	45 ^{j}	0.75 ^{a}	18	214	23.2
San Agustín[3]	24° 04’ 17”	110° 57’ 05”	46 ^{i}	0.53 ^{jkl}	160	182	24.2
El Cardon[3]	23° 14’ 20”	110° 10’ 54”	49.6 ^{e}	0.58 ^{gh}	7	180	24.2
Bahía Kino[4]	29° 00’ 16”	111° 55’ 08”	48.6 ^{f}	0.52 ^{klm}	5	155	23.7
Puerto Libertad[4]	29° 54’ 15”	112° 43’ 39”	50.2 ^{de}	0.64 ^{cde}	113	122	20
Clifton[5]	33° 03’ 80”	109° 17’ 48”	50.8 ^{cd}	0.48 ^{n}	1 055	306	19.2
Cave Creek[5]	33° 43’ 20”	112° 03’ 00”	53 ^{a}	0.63 ^{def}	771	312	20.3
Desert Museum[5]	32° 15’ 10”	111° 10’ 11”	49.6 ^{e}	0.57 ^{ghi}	858	244	21.1
First Water[5]	33° 28’ 40”	111° 35’ 10”	47.6 ^{gh}	0.53 ^{jk}	576	324	21.3
Globe[5]	33° 23’ 60”	110° 47’ 11”	51.4 ^{bc}	0.65 ^{cd}	1 082	394	16.6
Organ Pipe[5]	31° 56’ 11”	112° 47’ 21”	48.6 ^{f}	0.58 ^{q}	511	233	20.7
Superior[5]	33° 18’ 70”	111° 06’ 47”	48 ^{fgh}	0.65 ^{cd}	913	433	20.5
Tonto Forest[5]	33° 40’ 30”	111° 09’ 03”	51.8 ^{b}	0.68 ^{b}	678	368	20
SD[6]					397.6	98.3	3.37

[1]= California; [2]= Baja California; [3]= Baja California Sur; [4]= Sonora; [5]= Arizona; [6]= Standard deviation; [7]= % on seed weight; [8]= meters above sea level; [9]= mm year^{-1} (averages between 15 and 20 years); [10]= annual mean year^{-1} (averages between 15 and 20 years). [11]= column means with the same letter are not significantly different ($p< 0.05$) for the minimum significant difference test.

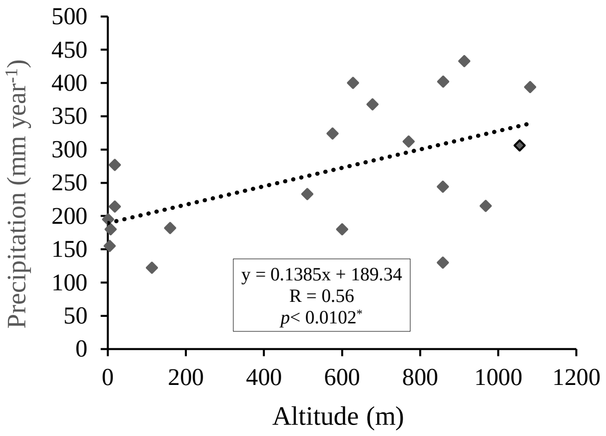

Figure 2. Correlation between mean annual rainfall and elevation of the terrain in native jojoba populations

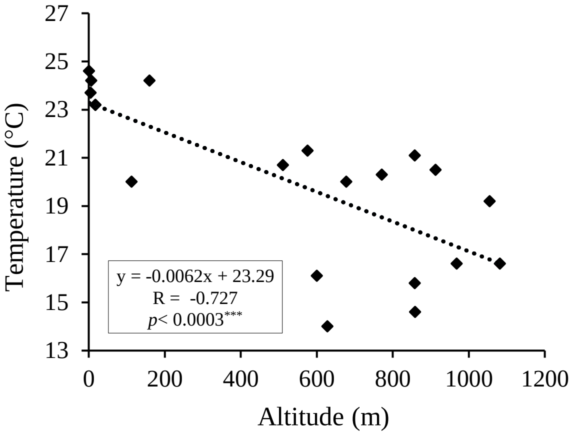

Figure 3. Correlation between mean annual temperature and elevation of the terrain in native jojoba populations.

The lowest contents were determined in the seeds of two sites located in Baja California Sur, San Agustin (46%) and El Gaspareño (45%), with significant differences between them ($p< 0.05$). This variability between extremes of up to 17.7% opens up interesting prospects for selection and genetic improvement. However, as has been demonstrated in other *viz*, moringa and chia species (Ayerza, 2019a, b), the oil content responds to an interaction between the genotype and the environment, so this relationship must be understood.

Thus it is must also bear in mind that these contents were obtained from plant seeds located in its dispersion area with variations in topography, soils, temperatures and rainfall (Table 1). Although the jojoba is a species of sexes in different feet and the control of the origin of the pollen has not been individualized in any work of the species; in other species, such as rape (*Brassica napus* L.)

The maternal factor was determined to involve 75% of the genetic variability of the oil content and respond to a genotype x environment interaction (Guo *et al.*, 2017). Previous studies have shown that photosynthesis in the silicone wall is a crucial contribution to the oil content (Hua *et al.*, 2012) and provides an explanation of the influence of maternal parents on the oil content. This influence has been determined in other species such as the sunflower (*Helianthus annus* L.) (Ramírez *et al.*, 2007).

In Table 2 (Ayerza, 1990c) we can see the oil contents obtained in a plantation located in Chancani, where 15 genotypes from seeds collected in the Tucson Mountains were measured, under rainfed conditions. A sample composed of seeds produced for five years from each plant was analyzed, obtaining a difference of 9.1% between the maximum (52.89%) and the minimum (48.47%).

Table 2. Average percentage of five years of oil production in 15 plants from the third year of planting, Chancani, Cordoba.

Plant	Oil (%)[2]	Seeds (kg plant^{-1})[3]
32	52.89	3.456
55	52.53	
48	52.52	
58	52.5	2.521
416	52.21	
119	51.7	
37	51.53	2.42
1112	51.1	
610	50.9	3.433
415	50.34	
35	50.3	
36	49.8	
410	49.71	1.949
310	49.71	2.029
380	48.47	
SD[1]	1.33	664.77

[1]= standard deviation; [2]= % of seed weight; [3]= Σ production 5 years.

This smaller difference compared to that in Table 1 can be explained by being plants from seeds with the same origin, grown in the same place and with the same agronomic management. No significant correlation was detected between oil percentage and accumulated seed production in the measured period. In the Table 3 (Ayerza, 1990b) shows the comparative contents of six genotypes, obtained annually for five consecutive years, under rainfed conditions.

Table 3. Variability of oil content between years in plants originating from seeds in Chancani, Cordoba.

Plant	1982	1983	1984	1985	1986	SD[1]
	Oil (%)[2]					
32	53.97^{a}[3]	52.89^{c}	53.2^{b}	51.2^{c}	53.2^{b}	1.03
36	49.8^{c}	49.8^{c}	52.4^{a}	50.6^{b}	46.4^{d}	2.18
38	49.7^{b}	40.6^{c}	51.9^{a}	49.7^{b}	50.4^{b}	4.48
310	47.24^{c}	49.71^{b}	52.8^{a}	49.7^{b}	49.1^{b}	2
48	52.9^{b}	55^{a}	53.5^{b}	50.8^{c}	50.4^{c}	1.92
610	46.52^{d}	50.9^{c}	53.4^{a}	52.3^{b}	51.4^{c}	2.63
SD[1]	2.97	4.95	0.63	0.98	2.29	

[1]= standard deviation; [2]= % on the dry weight of the seed.

There it can be seen that the comparative variability between years of the same genotype is strongly influenced by the genetic-environment interaction. The magnitude of the standard deviations of 1.03 and 1.92 corresponding to the annual yields of plants 32 and 48, respectively, demonstrate greater stability of oil yield than the other four genotypes. The opposite case was presented by plant 38, with a standard deviation equal to 4.48 and a difference of 25.4% between the highest and the lowest yield.

The genotypes were not coincident in the year of highest or lowest production, suggesting different responses of the genotype-environment interaction. These differences in the annual variability in oil production due to the genetic-environment interaction have been reported in other arid zone species such as the moringa and the olive tree (Ayerza and Sibbett, 2001; Ayerza, 2011).

In Table 4 (Ayerza, 1993) the results are seen in the content of seed oil with four levels of irrigation in Chancani. The plants came from seeds collected at the same location in Table 3 and descendants of original plants from the Tucson Mountains. Basically, a tendency to decrease in the oil content is seen with the increase in irrigation, slightly in 1986 and more pronounced in 1987, presenting the highest inter-annual standard deviation with the treatment of greater irrigation.

Table 4. Percentage of oil with four levels of irrigation in Chancani, Córdoba.

Year	0 mm	300 mm	600 mm	900 mm	SD[1]
	Oil (%)[2]				
1986	56.37	56.32	55.33	55.26	0.61
1987	50.49	49.87	49.79	40.09	4.99
SD[1]	4.16	4.56	3.92	10.73	

[1]= standard deviation; [2]= % on seed weight.

The magnitude of the standard deviations of the two measured years show a greater comparative dispersion between treatments for the year 1987. This suggests a greater nonconformity regarding the environmental conditions, essentially climatic. The year 1987 received late frosts, when the fruit was already in development, the rain (654 mm) was 142% higher with 52.3% more days with precipitation and 2 °C more of the maximum annual temperature compared to the previous year.

These climatic variations have been shown to influence the oil content of numerous species viz, sunflower, chia, moringa, soybean and olive (Thomas *et al.*, 2003; Kumar *et al.*, 2006; Ayerza, 2011, 2019a), at higher temperatures , lower oil yield (Ayerza, 2009, 2010); thus, it has also been verified that there is a high negative correlation between protein and oil content and that high rainfall strongly favors protein content.

High temperatures have been shown to negatively influence the oil content of the seeds of other species such as chia and moringa (Ayerza, 2001). These aspects could explain the differences between years and between treatments in this experiment. Likewise, in Table 5 comparing the oil content of eight clones in Zancas, Catamarca, under irrigation conditions, a significant difference ($p< 0.05$) of 13.8% between the highest and lowest content was determined.

Table 5. Variability of oil content between clones in Zancas, Catamarca.

Clone	Oil (%)[1]	Seeds (g $plant^{-1}$)
Coca-Huasi	56.2 [a2]	705 [a]
SF-5-133	54.1 [b]	383 [b]
SF-5-167	53.5 [b]	362 [bc]
SF-5-166	51.2 [c]	296 [bcd]
SF-5-192	50.4 [cd]	292 [bcd]
Llipta	50.3 [cd]	272 [cd]
Acullico	50.1 [cd]	227 [de]
SF-5-188	49.4 [d]	148 [e]

The Coca-Huasi clone was significantly ($p< 0.05$) higher than the other seven. The averages correspond to the production of three consecutive years (stakes of 3, 4 and 5 years of implanted clones between 25 and 30 years of age) originating from seed plants introduced in Chancani, from Tucson Mountains, with four plants per clone in a randomized statistical design.

This variation between clones (Table 6) was repeated in another comparative trial with irrigation and the same statistical design carried out for one year in the same locality, with five different clones of the same origin (Ayerza, 2001). The repeatability of the clone behavior in these two tests confirms the stability of the genotype x environment ratio.

Table 6. Variability of oil content between clones in Zancas, Catamarca.

Plant	Oil (%)[1]
SF-4-31	55.05 [a3]
SF-5-151-3	53.65 [a]
SF-5-121	50.8 [b]
SF-40	50.7 [b]
SF-6-245	49.85 [b]
LSD[2]	1.4

[1]= % on seed weight; [2]= minimal significant difference for $p< 0.05$; [3]= means with the same letter are not significantly different ($p< 0.05$) for Duncan's multi-range test.

In the Table 7 (Ayerza, 1996) compares the oil content between plants of the same clone, with irrigation. Four plants per clone were used in a randomized statistical design. The averages correspond to a composite sample of the production of three consecutive years of each plant. The statistical deviation between plants was 1.03 and 0.81% for clones A-SF5-151 and A-SF6-245 respectively, which demonstrated the highest productive stability of the second.

Table 7. Variability of oil content between plants of the same clone and between clones in Zancas, Catamarca.

Clone A-SF5-151		Clone A-SF6-245	
Plant	Oil (%)[2]	Plant	Oil (%)
PL-5	54.8	PL-6	50.6
PL-1	54.3	PL-4	50.5
PL-3	52.8	PL-7	49.2
PL-2	52.8	PL-3	49.1
SD[1]	1.03	SD	0.81
A-SF5-151	53.68 [a4]		
A-SF6-245	49.85 [b]		
LSD[3]	1.604		

[1]= standard deviation; [2]= % on seed weight; [3]= minimal significant difference for $p< 0.05$; [4]= means with the same letter are not significantly different ($p< 0.05$) for Duncan's multi-range test.

The difference between both clones resulted in a yield of 53.68% significantly ($p< 0.05$) higher for clone A-SF5-151, than 49.85% of clone A-SF6-245, as observed in Table 8. Production of oil from 13 of the clones highlighted by the yield of seeds from the plantation that produces under irrigation conditions approximately 46% of the total seed of Argentina (Ayerza, 2018c), was measured for one year in Aimogasta. This presented significant differences ($p< 0.05$) that varied its oil content 17% between extremes (Tobares *et al*., 2004) demonstrating that there is a strong selection differential in the clones used today.

Table 8. Fatty acid composition of oil from eight clones in Zancas, Catamarca.

Clone	Fatty acids				
	C16:0	C18:1	C20:1	C22:1	C24:1
	% of the total fatty acids				
SF-5-166	2.69 [a1]	9.99 [a]	68.02 [c]	3.74 [b]	15.57 [ab]
Acullico	1.5 [ab]	10.15 [a]	70.68 [abc]	3.3 [bc]	16.18 [ab]
SF-5-133	1.23 [ab]	8.71 [abc]	72.23 [ab]	2.87 [bc]	14.93 [b]
Llipta	1.09 [ab]	8.74 [abc]	71.03 [abc]	4.26 [ab]	14.65 [b]
Coca-Huasi	1.04 [ab]	7.01 [c]	73.68 [a]	2.1 [c]	14.37 [b]
SF-5-167	0.7 [ab]	8.63 [abc]	69.73 [bc]	5.81 [a]	15.06 [b]
SF-5-192	0.69 [b]	7.81 [bc]	71.2 [abc]	3.03 [bc]	17.27 [a]
SF-5-188	0.33 [b]	9.3 [ab]	69.6 [bc]	5.56 [a]	15.21 [b]

[1]= the averages of each column with the same letter are not significantly different ($p< 0.05$) for Duncan's multi-range test.

Unlike the lack of relationship between oil content and seed production determined in the tests in Table 2 and the work with clones carried out in Aimogasta (Tobares *et al*., 2004), in Figure 4, formed with the data from Table 5 a very high positive relationship was determined (R^2= 0.916;

$p < 0.0023^{**}$). This different behavior could be partly explained based on the fact that these eight clones were selected for oil production per plant and not for seed production, as they were in the other two works.

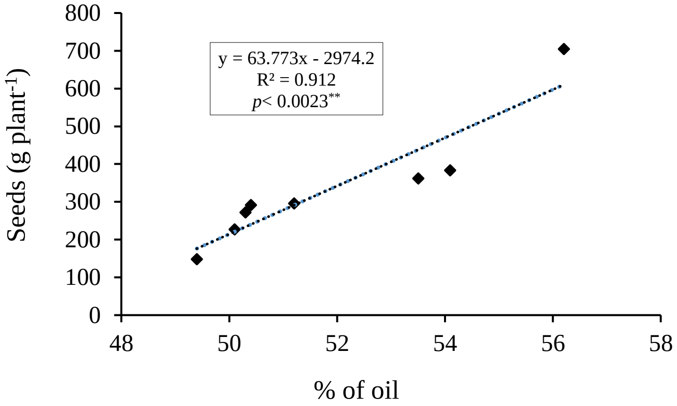

Figure 4. Relationship between oil content and seed yields in eight jojoba clones in Zancas, Catamarca.

In the Table 8 (Ayerza, 1996) includes the fatty acid composition of jojoba oil from eight clones implanted under irrigation in Zancas. The significant statistical differences ($p < 0.05$) between clones located in the same ecosystem, for each of the five main fatty acids determined, allows us to think about their use in genetic improvement programs. In the case of eicosenoid fatty acid, which is the majority, the significant difference ($p < 0.05$) was 8.32% between extremes.

This significant variability ($p < 0.05$), although in a lower percentage in the case of eicosenoid fatty acid (4%), was also reported when the composition of fatty acids was compared when analyzing 13 of the most productive clones in terms of seeds, implanted in Aimogasta (Tobares *et al*., 2004) where at present the totality of the commercial production of jojoba in Argentina is concentrated. When the composition of the wax esters in the clones in Table 6 was compared, significant differences ($p < 0.05$) were also detected between genotypes for the different esters.

These differences were also detected between clones implanted in Ica, Peru and originating in Zancas, Catamarca (Ayerza, 2001). Pollen has a much greater influence on the composition of the oil than on the content (Xie *et al*., 2019), which is why the use of artificial pollination with material from proven parents is important. The implementation of this technology has demonstrated its efficiency in jojoba by increasing seed production (Coates *et al*., 2006; Coates and Ayerza, 2008).

Conclusions

The present study carried out with the available information and the one generated here, analyzes the origin of the jojoba genetics introduced in Argentina from 1976; through time to clones in production today in Aimogasta- Bañado de los Pantanos, regarding oil yield. It demonstrates the existing variability in this production factor and the importance of incorporating it into future selection plans.

Knowing and raising the oil contents and even its chemical composition, could allow the formation of content standards and the producer's access to content bonuses as it happens with other oilseeds, viz, sunflower, rapeseed, soy, peanut, etc. After all, today the only reason for the production of jojoba seed is the use of its oil.

The formation of a jojoba germplasm bank from the natural populations of the Sonoran Desert is the obvious option to maintain genetic variability in selection programs and safeguard the genes necessary for the future of the crop. Jojoba is presented as a promising crop for arid and semi-arid subtropical areas due to its ability to produce high value oil in these difficult and decertified regions.

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