industrial crops and products 27 (2008) 364–370

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/indcrop

Supplemental pollination-increasing jojoba (*Simmondsia chinensis* L. [schneider]) seed yields in the Arid Chaco environment

*Wayne Coates**, *Ricardo Ayerza (h)*

The University of Arizona, Office of Arid Lands Studies, Tucson, AZ 85706, USA

ARTICLE INFO

Article history:
Received 11 September 2007
Received in revised form
18 December 2007
Accepted 19 December 2007

Keywords:
Jojoba
Supplemental pollination
Yield increase
Arid climates

ABSTRACT

Jojoba (*Simmondsia chinensis* L. [Schneider]) is a wind-pollinated perennial shrub native to the Sonoran Desert. In recent years commercial plantations in Arizona and Catamarca, Argentina have dramatically decreased in size and number, going from 13,000 ha in the early 1980s to about 2,300 ha today. The main reason for this decrease is yields being lower than expected, with low pollination percentages considered the main source of the problem, although use of inferior genetic material has contributed to the problem. Artificial or supplemental pollination has been used successfully in other crops to increase yields, and it was thought that this could also be used for jojoba. A trial was carried out over two seasons in which pollen collected in Arizona, was mechanically applied to commercial fields in Catamarca. The first year yields were significantly ($P < 0.05$) greater in the fields in which pollen had been applied, than in the controls. The second year yields were not measured. Rather the number of capsules with fruit, aborts, and empty capsules were counted on a number of randomly selected branches. This technique gives a good estimate of yield, and the results showed that pollen application significantly ($P < 0.05$) increased expected yields. In conclusion, application of supplemental pollen increases jojoba yields and hence should be considered a viable option for commercial plantations. Additional work is required, however, to determine the correct application rate so as to minimize collection costs, and determine when application should take place to optimize efficacy.

1. Introduction

Jojoba (*Simmondsia chinensis* L. [Schneider]) is a perennial shrub native to the Sonoran Desert, which is located in the southwestern USA and northwestern Mexico. The plant is unique because 50% of the weight of its seeds is an almost odorless, colorless liquid wax, composed mainly of monoesters of C:20 and C:22 straight-chain alcohols and acids (Wisniack, 1987).

Jojoba is a dioecious, wind-pollinated plant. Flowers of both male and female plants are small and lack both nectaries and petals (Gentry, 1958). Female flowers consist of one to four large bracts, four to six sepals, and a three-locular superior ovary surmounted by three (rarely, four) long styles. Male flowers develop on racemose inflorescences, and each one consists of four to six sepals and eight to 16 large, erect anthers (Benzioni and Dunstone, 1986). Typically there are three anatropous ovules per ovary. One can also find four ovules per ovary, on occasion. Although three ovules are normally produced, typically only one of the three ovules will be fertilized and produce a capsular fruit (Buchmann, 1987).

* *Corresponding author*. Tel.: +1 520 455 5050; fax: +1 520 455 5533.
E-mail address: wcoates@u.arizona.edu (W. Coates).

0926-6690/$ – see front matter
doi:10.1016/j.indcrop.2007.12.002

In Catamarca, Argentina, which is located in the Arid Chaco ecosystem, flowering generally lasts 4–5 weeks; however, depending on ambient temperatures flowering can vary from as short as 30 days, to as long as 45 days (Ayerza, personal communication, 2005). The reason for this is that stigmatic receptivity is very dependent on ambient temperatures prior to anthesis, and during bloom (Buchmann, 1987). In the Sonoran Desert female flowers are receptive for a period of 3–6 days, while in the Arid Chaco the duration is less than 4 days (Ayerza, 1990).

In recent years commercial plantations in the Hyder Valley in Arizona and in Catamarca, Argentina have dramatically decreased in size and number, going from 10,000 ha in the early 1980s to about 2000 ha in Arizona, and from 3000 ha in Catamarca in the late 1990s to approximately 300 ha today. The main reason for this reduction is yields being lower than expected, and as a result many fields were abandoned. Reduced yields have been attributed to two factors: poor genetic material, and low pollination percentages because of an insufficient number of male plants.

Supplemental pollination, applied by mechanical means, could improve jojoba yields as this has been shown effective for other wind-pollinated plants such as olives, almonds, dates, and pistachios. To determine whether supplemental pollination could be beneficial for jojoba, a bi-national project was set up in Arizona, USA, and Catamarca, Argentina. A previous paper reported the results of a trial in which pollen collected in Catamarca was applied in the Hyder Valley of Arizona (Coates et al., 2006). Herein are presented the results of trials conducted over two seasons in which pollen collected in Arizona, was applied to commercial fields in Catamarca.

2. Materials and methods

Pollen was mechanically applied to a commercial plantation in the Central Valley of Catamarca, Argentina (28°28′S latitude, 65°46′W longitude, and 500 m of elevation), which is located in the Arid Chaco ecosystem. The test fields had been planted between March 2 and 5, 2001. Distances between rows and within plants in rows were 5 and 1.2 m, respectively (Table 1). Rows ran in an east-west direction following the natural field slope.

The test area was comprised of eight fields of female plants of the clone Ambato 10, which were located adjacent to one another. Five fields were pollinated, and three fields were left as controls. Each field had a mean size of 1.6 ha (CV: 12.2%), and consisted of 16 rows. Three rows of male plants were located in rows 1, 8, and 16. Row 8 had plants established from cuttings, while rows 1 and 16 were established from seeds. All of the male plants originated from shrubs planted in the area.

Test fields were separated from one another by a 50 m wide strip of natural Arid Chaco vegetation (trees, shrubs, and herbaceous species), which serves as a windbreak. As rows 1 and 16 were established from seed, and are relatively close to natural vegetation, the plants were underdeveloped and had a minimal number of male flowers open and releasing pollen when application took place. The presence of the natural vegetation led to the poorer development of the outside rows primarily because of the competition for the irrigation water.

2.1. Year I

Flower opening began on August 20, with approximately 5% of flowers open, and finished on September 17 when approximately 95% of the flowers had opened. One application on each plot was made, on 27 August on fields B7, C7, and F8, and on 29 August on fields G8 and F8 (Table 1). Pollen was applied at a mean rate of 70 g/ha (CV: 13.1%), with the variation coming about because of variations in plot size and driver performance (Table 1). The pollen applicator is described by Coates et al. (2006). Wind speed, temperature and humidity during application, as well as throughout the flowering period, were recorded (Table 2).

The pollen used for the trial came from the Hyder Valley, Arizona, USA (33°N latitude, 113°W longitude, and 200 m elevation), which is located in the Sonoran Desert ecosys-

Table 1 – Catamarca field characteristics

Field	Area (ha)	Female plants (plants/ha)	Female:male (ratio)	Planting date (m/d/y)	Clone	Design (m)	Pollen applied (g/ha)	
							2005/06	2006/07
C[a] $_{A7}$	1.85	1,416	5.3:1	3/2/01	Ambato 10	1.2 × 5	–	–
C $_{E8}$	1.48	1,416	5.3:1	3/3/01	Ambato 10	1.2 × 5	–	–
C $_{F9}$	1.49	1,416	5.3:1	3/5/01	Ambato 10	1.2 × 5	–	–
P[b] $_{B7}$	1.65	1,416	5.3:1	3/3/01	Ambato 10	1.2 × 5	66.7	200.1
P $_{C7}$	1.63	1,416	5.3:1	3/3/01	Ambato 10	1.2 × 5	67.6	202.8
P $_{F8}$	1.88	1,416	5.3:1	3/4/01	Ambato 10	1.2 × 5	58.4	175.2
P $_{G8}$	1.41	1,416	5.3:1	3/4/01	Ambato 10	1.2 × 5	78.2	234.6
P $_{G9}$	1.39	1,416	5.3:1	3/5/01	Ambato 10	1.2 × 5	79.3	237.9
CV%[c]	12.2						13.1	13.1

[a] C: control fields.
[b] P: pollinated fields.
[c] Coefficient of variation (%).

Table 2 – Climatic conditions when supplemental pollen was applied

Field	Pollen application (d/h)	Winds (km/h)	Temperature (°C)	RH[a] (%)
Year I				
P[b]7B	8/27 (5:00 p.m.)	7 W	36.2	9
P 7C	8/27 (5:30 p.m.)	8 W	35.6	8.5
P 8F	8/27 (6:00 p.m.)	22 W	35	8
P 8G	8/29 (6:30 p.m.)	4.5 W	17.4	37.5
P 9G	8/29 (7:00 p.m.)	>1	16.9	42
Year II				
P 7B	9/11 (3:00 p.m.)	>1	31.6	18
	9/18 (8:30 a.m.)	26 NE	19.8	22
	9/22 (2:45 p.m.)	8 SE	30	17
P 7C	9/11 (3:15 p.m.)	>1	31.6	18
	9/18 (8:50 a.m.)	26 NE	19.8	22
	9/22 (3:00 p.m.)	9 S	30.2	17
P 8F	9/11 (3:30 p.m.)	4 SE	31.9	18
	9/18 (9:15 a.m.)	30 NE	21.2	29
	9/22 (3:10 p.m.)	9 S	30.2	17
P 8G	9/11 (3:45 p.m.)	4 SE	31.9	18
	9/18 (9:30 a.m.)	32 N	22.8	22
	9/22 (3:30 p.m.)	8 S	30.9	15
P9G	9/11 (4:05 p.m.)	7 SE	32.2	17
	9/18 (9:50 a.m.)	32 N	22.8	22
	9/22 (3:50 p.m.)	8 S	30.9	15

[a] Relative humidity.
[b] Pollinated field.

tem. Collection took place between 16 March and 25 March 2004 from approximately 20-year-old male plants that had been propagated from seed. The vacuum system described by Coates et al. (2006) was used for collection. During the collection period the pollen was transported daily to a freezer located in the Office of Arid Lands Studies at the University of Arizona. In July 2005 the pollen was packed on blue ice and transported via air freight from Tucson, Arizona to Buenos Aires and then to Catamarca, Argentina where it was placed in a freezer until applied. As required by the Argentine Government, the pollen was inspected by the USDA prior to shipment, and a Phytosanitary certificate was issued allowing it to be imported.

Seed yields were determined by harvesting the crop once it had fallen from the plants onto the soil surface. This is the normal practice in the region. Following harvest the seed was cleaned, placed in 50 kg bags, then stored until reaching a moisture content of 4%. The seeds were then weighed, and samples obtained to determine 100 seed weight, wax content and composition.

Analyses of the seeds were performed by International Flora Technologies Inc., Chandler, Arizona, by Dr. Robert Kleiman. The oil (wax-ester) content was determined by AOCS (1984) method Ac 3–44, and a Hewlett-Packard 5890 gas chromatograph, with a flame ionization detector at 350 °C. The capillary column used was a 30 m × 0.25 mm ID BPX with 0.25 μm film thickness (Palo Altro, USA), run isothermally at 340 °C.

Each variable was compared by analysis of variance. When the F-value was significant, means were separated using Student–Newman–Keuls test. Correlation coefficients were used to assess whether a relationship existed between measured parameters (Cohort Stat, 2006).

2.2. *Year II*

In order to verify that the application procedure was indeed valid, and that the results from 2005 could be replicated, the same fields were again tested in 2006. The pollen was the same stock as used the first year, and had been stored in a freezer between seasons. To determine pollen viability prior to application an analysis was performed at the University of Buenos Aires using the technique developed by Greissel, which is described by Kearns and Inouye (1993). Results were 65.9% viability at 5 min and 22.4% at 30 min. Because of the reduced viability, pollen application amounts were increased 3-fold, with the same quantity that was applied during the first year applied during each of the three applications that took place the second year (Table 1). The same machine and operating procedures were used as in the first year. Weather conditions during the three applications are shown in Table 2, with flower opening beginning on September 8, and finishing on October 2.

Evaluations to determine effectiveness of the treatment were made 69 days following the last application. For each treatment and replication, 10 shrubs from each of the 13 rows (a total of 130 shrubs per replication; 650 and 390 shrubs for the pollinated and control plots, respectively) were selected at random. On each shrub one branch (approximately 0.30 m long) on the northern side, and one on the southern side, was selected at random for sampling. The number of capsules with fruit and aborts (those that were pollinated and began to produce a seed but did not reach maturity), as well as empty capsules (those that were not pollinated) on each branch were counted. A total of 1300 and 780 branches per treatment were selected from the treated and control plots, respectively.

Table 3 – Jojoba seed production when supplemental pollen from Arizona was and was not applied in Catamarca

Treatment	Field size (ha)	Yield (kg/ha)	Seed weight (g/100 seeds)	Seeds per capsule (%)	
				Single	Two or more
Control	1.61a[a]	55b	73a	4.3a	95.7a
Pollinated	1.59a	137a	70a	3a	97a
LSD[b]	0.408	37.657	14.28	6.139	6.139

[a] In a column, means with the same letter are not statistically different ($P<0.05$) according to Student–Newman–Keuls test.
[b] Least significant differences for $P<0.05$.

Each variable was compared by analysis of variance. When the F-value was significant, means were separated using the Least Significant Test (Cohort Stat, 2006).

3. Results

3.1. Year I

Seed yield, 100 seed weight, and number of seeds per capsule are presented in Table 3. Seed yield was significantly higher ($P<0.05$) in the pollinated plots compared to the control. No significant differences ($P<0.05$) among treatments were detected for 100 seed weight or number of seeds per capsule.

The comparison between pollen application days (August 27 and 29) and yield is shown in Table 4. Yield was significantly correlated with date of application (0.97**). Correlations between seed yield and individual climatic parameters showed temperature and humidity at time of pollen application to be significant. Positive correlations between yield and humidity (0.95*), and a negative correlation between yield and temperature (−0.98**) were found. The correlation between yield and wind speed was not significant (-0.53^{NS}), nor was the correlation between quantity of pollen applied and yield (0.36^{NS}).

No significant ($P<0.05$) differences among treatments were detected for either wax-ester content or composition.

3.2. Year II

The mean number of capsules with fruit and aborted, as well as empty capsules are shown in Table 5. Fruiting capsules were significantly higher ($P<0.05$) and empty capsules were significantly lower ($P<0.05$), in the pollinated fields, compared to the control. No significant differences ($P<0.05$) among treatments were detected for aborted capsules. Sampled branches that received supplemental pollination produced significantly ($P<0.05$) more fruited capsules than the control when the south and north sides were compared separately, with pollinated branches showing 1.6- and 3-fold more fruited capsules for the southern and northern sides, respectively. Empty capsules were significantly ($P<0.05$) higher on branches in the control fields for both the north and south sides of the plants when considered separately.

The comparison of fruited, aborted, and empty capsules between shrub sides, within treatments, is presented in Table 6. For the control, significantly ($P<0.05$) fewer fruited capsules were found as were significantly ($P<0.05$) higher empty capsules on the north side of the shrubs, compared with the south side; no significant ($P<0.05$) difference in aborted capsules was detected. This is very different from the pollinated treatment in which no significant ($P<0.05$) difference in capsules was found between the north and the south sides.

Table 4 – Correlation between seed yield and weather parameters for applications made during the first year of the study

Parameters	Correlations: Coefficient
Yield vs. humidity	0.95*
Yield vs. temperature	−0.98**
Yield vs. winds	-0.53^{NS}
Yield vs. day of pollination	0.97**
Yield vs. quantity of pollen/ha	0.36^{NS}

*Significant at $P<0.01$, **significant at $P<0.05$, ^{NS}not significant.

4. Discussion

In general the seed yields were very low by commercial standards and came about primarily because of a late frost, which damaged many of the female flowers. Still, application of supplemental pollen to jojoba significantly ($P<0.05$) increased seed production (Table 3) with yields being 2.5 times that of the control. This is not unlike a number of other species which have shown dramatic yield increases when supplemental pollination has been applied: Douglas Fir (*Pseudotsuga menziesii* [Mirb]. Franko) (Webber, 1987); Stika-Spruce (*Pinus sylvestris* L.) (El-Kassaby and Reynolds, 1990); almonds (*Amygdalus communis* L., Rosaceae) (Vaknin et al., 2001); pistachio (*Pistacia vera* L.) (Vaknin et al., 2002); olives (*Olea europaea* L.) (Ayerza and Coates, 2004).

Indications of increased jojoba seed production brought about by supplemental pollination were reported by Coates et al. (2006) in a plantation located in Hyder Valley, Arizona; however, yield increases were less dramatic and were not consistent between years. Differing results between the Arizona and Catamarca trials might be due to differences in female–male ratio, and distance between plants. The Arizona field had a female–male ratio of 5:1, while the Catamarca field had a ratio of 13:1 (while male to female rows were in the ratio of 5.3:1, given that the outside rows were producing no pollen, the production ratio was 13:1). Additionally, the maximum distance between plants of a different sex was 12 m,

Table 5 – Comparison of the percentage of fruiting, aborted, and empty capsules between rows which had supplemental pollen applied (pollinated), and those which were naturally pollinated (control) during the second year

Treatment	Total (%)			South side (%)			North side (%)		
	Fruits	Abort[a]	Empty[a]	Fruits	Abort	Empty	Fruits	Abort	Empty
Control	23.7b[b]	39.1a	37.2a	32.1b	41.3a	26.6a	16.0b	37.0b	47.0a
Pollinated	49.1a	45.1a	5.8b	49.8a	43.3a	6.9b	48.4a	46.8a	4.8b
S.D.[c]	6.96	7.36	6.39	10.42	10.66	8.99	9.13	10.21	8.81

[a] Aborts (those that were pollinated and began to produce a seed but did not reach maturity), empty (those that were not pollinated).
[b] In a column, means with the same letter are not statistically different ($P < 0.01$) according to the Least Significant Test.
[c] Least significant differences for $P < 0.05$.

while in Catamarca the distance between sexes was more than 15 m for 61% of the plants. Studies in Israel have shown that fruit set in jojoba is a function of distance between female and male rows (Benzioni and Ventura, 1998).

The dramatic yield increase reported herein could be explained by the higher female:male ratio in combination with the weather conditions not only over the flowering period in general, but in particular during the times when supplemental pollen was applied. As demonstrated in other crops, flower set in wind-pollinated species is strongly influenced by weather during flowering (Tormo-Molina et al., 2001). Significantly ($P < 0.05$) higher seed yields (25% increase) were found for plants pollinated on 29 August, compared with those pollinated on 27 August (data not shown). Given these data, yields were significantly correlated with weather parameters since they were positively correlated (0.95%) with relative humidity, and negatively correlated (−0.98%) with temperature and wind speed (−0.53%) (Table 4)

Coates et al. (2006) reported a dramatic decrease in jojoba pollen viability, nearly 10-fold, following days with hot dry winds in the Hyder Valley of Arizona. These findings are in agreement with those of others working with different species as they have shown the effects of weather on the pollination process. For example, in corn a pollen dessication effect has been found, with pollen viability decreasing faster at low RH and high temperature (Fonseca and Westgate, 2005; Aylor, 2003). Similarly, *Cupressus* spp. pollen viability has shown a strong negative correlation with air temperature (Cariñanos et al., 2004).

Wind speed has been reported by Tormo-Molina et al. (2001) as the most relevant negative factor influencing levels of pollen in the atmosphere in plants such as *Plantago* spp., *Chenopodium* spp., and *Amaranthus* spp. The authors attributed this finding to pollen capture and release by the flowers. Research on a number of species has shown decreased pollen capture as wind speed increases. For anemophilous plants, winds are needed to disperse pollen. However, experimental data have shown winds to be effective only when they are less than 20 km/h (Tormo-Molina et al., 2001). For the current trial, 80% of the days during flowering had wind speeds greater than 20 km/h, and 41% had wind speed greater than 30 km/h (data not shown). The significantly ($P < 0.05$) lower seed production found with the control could be associated with the high wind speed, which negatively affected pollen capture.

A contributing factor could be that in desert areas such as the Arid Chaco winds frequently create dust storms, which tend to form a dust covering over the entire plant. Jojoba germination trials in Israel showed increased germination after washing the inflorescences (Vaknin et al., 2003). Hence, this is another wind factor that could have negatively affected natural pollination.

Another factor that affects natural pollen availability is rain. Buchmann (1987) reported that airborne jojoba pollen counts dropped dramatically (from 267 grains/m^3/h to 7 grains/m^3/h) for at least 18 h following rain. Since a rain event occurred (data not shown) during the flowering period, a "washout" phenomenon could have reduced pollen availability, effectively decreasing pollination days during flowering.

Lack of a significant ($P < 0.05$) difference in wax-ester content and composition (Table 5) between treatments shows pollen source did not affect these characteristics, since both treatments were the same female clone. Miwa (1980) suggested that much of the variation in jojoba esters is due to temperature, rather than genotype. Ayerza (2001) analyzed

Table 6 – Comparison between row sides of the percentage of fruiting, aborted, and empty capsules that had supplemental pollen applied (pollinated), and those that were naturally pollinated (control) the second year

Treatment	Control (%)			Pollinated (%)		
	Fruits	Abort[1]	Empty[1]	Fruits	Abort	Empty
North side	16b[2]	37a	47a	48.3a[1]	46.9a	4.8a
South side	32.1a	41.3a	26.6b	49.8a	43.3a	6.9a
S.D.[3]	10.15	12.18	12.59	6.77	6.73	4.69

[1]Aborts (those that were pollinated and began to produce a seed but did not reach maturity), empty (those that were not pollinated); [2]In a column, means with the same letter are not statistically different ($P < 0.05$) according to the Least Significant Test; [3]least significant differences for $P < 0.05$.

wax-ester content and composition of 10 clones grown in two ecosystems, the Arid Chaco of Argentina and Atacama Desert in Peru. He also reported greater differences in wax ester content and composition between ecosystems, than from different clones growing in the same location.

The second year results, Table 5, show 2.1 times the number of fruited capsules in the pollinated treatment, than in the control. These capsule measurements, which were taken 69 days following pollination, provide accurate crop yield estimates and confirm the dramatic increase in seed yield found during the first year's trial. The lack of a significant ($P < 0.01$) difference between treatments in capsules aborted, and the significantly ($P < 0.01$) higher percentage of empty capsules found on the branches within the control treatment (6.4 times) indicate how strong an influence pollen application had on flower set. This effect was higher on the south side of the rows than on the north side, with 3-fold and 1.6-fold more fruits found for the treated and control fields, respectively.

The significant ($P < 0.05$) difference in percentage of fruiting and empty capsules detected between shrub sides in the control treatment, but not in the pollinated treatment, could be attributed to wind affecting the natural pollination process differently on each side of the shrubs. In general winds during the pollination season are from the N to the NE. The north winds are mostly dry and warm, and these characteristics intensify during the September to December time period (SMN, 1986). Winds such as these have been shown to negatively effect production on the north side of other tree crops in the Arid Chaco ecosystem (Giunta and Giunta, 1977), as well in other ecosystems (Ayerza and Coates, 2004).

The significantly higher ($P < 0.05$) abortion percentage found on the north branches of the pollinated treatment cannot be directly explained from the data (Table 5). Capsule position on the branches was not measured, so the results could be related to a higher number of flowers being set on the periphery of the shrubs in the pollinated treatment. Peripherally located flowers had less protection from northern winds, compared with flowers located in the interior of the shrub canopy. The result could be the higher abortion percentage.

Lack of a significant ($P < 0.05$) difference in overall abortion percentage between shrub sides suggests a genetic mechanism of regulation of this phenomenon, rather than a climatic event *per se*. Variations in flower set percentage of 46.7–87.1%, were reported when flowers of one jojoba clone were hand pollinated with pollen collected from six different male plants (Vaknin et al., 2003). Others have reported variations in flower set percentage of 44.3–70.3% between years for one jojoba clone under natural pollination conditions (Benzioni and Ventura, 1998). If aborted capsule percentage is added to fruiting capsule percentage, flower set percentage for the trial was 94.2% and 62.8% for the pollinated and control treatments, respectively.

5. Conclusions

As has been demonstrated for other tree crops, this study has shown that supplemental pollination of jojoba dramatically increases seed production, especially under the conditions of the Arid Chaco of Argentina. Hence, use of supplemental pollination could provide growers with increased jojoba yields in other hot and windy environments in which jojoba might be planted.

Supplemental pollination could dramatically and rapidly increase yield in number of commercial jojoba plantations around the world which are low yielding, mainly because of their high female:male plant ratio. Planting additional males would be another option; however, a period of 3–6 years would be required for them to produce sufficient pollen to be effective. Although planting more males would increase yields, it also reduces the number of females in a given field, thereby decreasing production per hectare.

Before this agronomic practice should be routinely adopted for jojoba, as it now is in olives, almonds, pistachio, and other orchards, further research is necessary. This is necessary not only to understand the jojoba pollination process more completely, but also to determine doses and timing of pollen application so as to optimize the process and minimize the cost of pollen collection.

Acknowledgments

These results are part of a project partly supported by a grant from the Arizona Department of Agriculture Office of Marketing and Outreach through Congressional appropriation pursuant to PL 107-25. Support of Fincas de Ambato S.A., Catamarca, Argentina, and International Flora Technologies, Ltd., Chandler, Arizona, USA are also appreciated.

REFERENCES

AOCS, 1984. Official Methods of AOC. American Oil Chemists' Society, Champaign, Illinois, USA.

Ayerza, R.(h), 1990. La Jojoba: ecología, manejo y utilizacion. Orientación Gráfica Editora, Buenos Aires, Argentina.

Ayerza, R.(h), 2001. Seed wax ester composition of ten jojoba clones growing in two arid ecosystems of South America. Trop. Sci. 41, 1–4.

Ayerza, R.(h), Coates, W., 2004. Supplemental pollination – increasing olive (*Olea europaea* L.) yields under hot arid environments. Exp. Agric. 40, 481–491.

Aylor, D.E., 2003. Rate of dehydration of corn (*Zea mays* L.) pollen, in the air. J. Exp. Bot. 54, 2307–2312.

Benzioni, A., Dunstone, R.L., 1986. Jojoba: adaptation to environmental stress and the implications for domestication. Quart. Rev. Biol. 61 (2), 177–199.

Benzioni, A., Ventura, M., 1998. Effect of the distance between female and male jojoba plants on fruit set. Ind. Crops Prod. 8, 145–149.

Buchmann, S.L., 1987. Floral biology of jojoba (*Simmondsia chinensis*), an anemophilous plant. Desert Plants 8, 111–124.

Cariñanos, P., Galan, C., Alcazar, P., Dominguez, E., 2004. Airborne pollen records response to climatic conditions in arid areas of the Iberian Peninsula. Environ. Exp. Bot. 52, 11–22.

Coates, W., Ayerza, R.(h), Palzkill, D., 2006. Supplemental pollination of jojoba – a means to increase yields. Ind. Crops Prod. 24, 41–45.

Cohort Stat, 2006. Cohort Stat 6.311. Cohort Software Inc., Monterey, California, USA.

El-Kassaby, Y.A., Reynolds, S., 1990. Reproductive phenology balance, and supplemental mass pollination in a Stika-Spruce seed-orchard. Forest Ecol. Manage. 31, 45–54.
Fonseca, A.E., Westgate, M.E., 2005. Relationship between desiccation and viability of maize pollen. Field Crops Res. 94, 114–125.
Gentry, H.S., 1958. The natural history of jojoba (*Simmondsia chinensis*) and its cultural aspects. Econ. Bot. 12, 261–291.
Giunta, R., Giunta, R.C., 1977. Ensayo de pasturas para zona semiarida y control de erosion eolica en La Rioja. Instituto de Investigaciones Agropecuarias 33, 350–362.
Kearns, C., Inouye, W., 1993. Techniques for Pollination Biologists. University Press, Bolder, Colorado, USA.
Miwa, T.K., 1980. Jojoba: Fundamental and Applied Research. Jojoba Plantation Products, Inc., Los Angeles, California, USA.
SMN-Servicio Metereologico Nacional, 1986. Estadisticas Metereologicas 1971–1980. Fuerza Aerea Argentina, Buenos Aires, Argentina.
Tormo-Molina, R., Silva-Palacios, I., Munoz-Rodriguez, A.F., Tavira-Munoz, J., Moreno-Corchero, A., 2001. Environmental factors affecting airborne pollen concentration in anemophilous species of *Plantago*. Ann. Bot. (Lond.) 87, 1–8.
Vaknin, Y., Gan-Mor, S., Bechar, A., Ronen, B., Eisikowitch, D., 2001. Improving pollination of almond (*Amygdalus communis* L.), Rosaceae) using electrostatic techniques. J. Hortic. Sci. Biotech. 76, 208–212.
Vaknin, Y., Gan-Mor, S., Bechar, A., Ronen, B., Eisikowitch, D., 2002. Effects of pollen supplementation on cropping success and fruit quality of pistachio (*Pistacia vera* L.; Anacardiaceae). Plant Breeding 121, 451–455.
Vaknin, Y., Mills, D., Benzioni, A., 2003. Pollen production and pollen viability in male jojoba plants. Ind. Crops Prod. 18, 117–123.
Webber, J.E., 1987. Increasing seed yield and genetic efficiency in Douglas-Fir seed orchards through pollen management. Forest Ecol. Manage. 19, 209–218.
Wisniack, J., 1987. The Chemistry and Technology of Jojoba Oil. American Oil Chemists' Society, Champaign, Illinois, USA.