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ELSEVIER
Industrial Crops and Products 24 (2006) 41–45
INDUSTRIAL CROPS AND PRODUCTS
AN INTERNATIONAL JOURNAL
www.elsevier.com/locate/indcrop

Supplemental pollination of jojoba—A means to increase yields

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Received 14 January 2005; accepted 28 December 2005

Abstract

Jojoba (*Simmondsia chinensis* (Link) Schneider) is a perennial evergreen shrub native to the Sonoran Desert of the southwestern U.S. and northwestern Mexico. Jojoba is dioecious, with male and female flowers present in separate plants, and is wind pollinated. Possibly, much of the yield variation detected in commercial fields is due to pollination problems. Supplemental, mechanically applied pollen is an alternative that could improve fruit set, and hence increase yield. Pollen was mechanically collected in Catamarca Argentina and applied in Arizona during bloom in 2003 and 2004. The flower set was very good for both treated and untreated plants, and supplemental pollen did not consistently provide significant increases in the number or percentage of flowers pollinated. These results were presumably due to sufficient pollen in the test fields coming from pollinator rows of male plants. Weather condition at the time of pollen harvest strongly influenced pollen quality. Low pollen viability was observed when pollen was harvested following a two-day period with hot, dry winds. This indicates that pollen collection must be timed appropriately for sufficient viable pollen to be available for supplemental use.

Keywords: Jojoba; Pollination; Yield; Arizona; Argentina

1. Introduction

Jojoba (*Simmondsia chinensis* (Link) Schneider) is a perennial shrub native to the Sonoran Desert of the southwestern U.S. and northwestern Mexico. The plant is dioecious, with small male and female flowers produced in separate plants, and is strictly a wind pollinated plant (Buchmann, 1987). The seeds contain a unique liquid wax or jojoba oil, and its derivatives have a wide range of current and potential uses. Jojoba oil is used extensively in the cosmetic industry due to its dermatological properties (Tobares et al., 2004), but can also be used as a high quality lubricant.

Jojoba has been grown commercially in Arizona and California for over two decades. However, the planted area has decreased from 10,000 ha in the early 1980s, to about 2000 ha today. The decrease has been attributed to the fact that yields have been lower than expected, and as result many fields have been taken out of production. One reason for low yields is that all of the initial fields were sown with seeds obtained from germplasm of unknown and mixed genetic background. Thus the plants in these fields were very heterogeneous. The fields also had an approximate 50–50 mixture of male and female plants with the majority of the female plants having low-yielding capacity.

An important production problem has been inconsistent yields. In certain years yields were high, whereas in others production is poor. One possibility is that seed yield variation is due to pollination problems.

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doi:10.1016/j.indcrop.2005.12.002

For wind pollinated plants such as jojoba, the concentration of airborne pollen grains has a negative, exponential distribution relative to distance from male plants. Benzioni and Ventura (1998) reported that jojoba pollen availability affects fruit set, and that yield decreases significantly at distances greater than 27 m from the male plants. Thus if the wind blows in only one direction, for a 4 m row spacing, a maximum of seven rows between male rows should be used. Younes and Palzkill (1990, unpublished) found yield was still low with even closer male to female spacing. In this case, eight female clones were studied at eight distances and eight directions from a pollen source. A 60% decrease in seed yield occurred as the distance from the male source doubled from 5 to 10 m.

Supplemental pollination by mechanical means is an alternative that could improve fruit set, and hence yield for wind-pollinated plants. Such an approach has been shown to work for olives in California (Sibbett et al., 1992), almonds in Israel (Vaknin et al., 2001), dates in the United Arab Emirates (Haffar et al., 1997) and pistachios in California (Vaknin et al., 2002), thus we postulated that a similar procedure could also work for jojoba. To determine whether supplemental pollination is beneficial for jojoba seed production, a project was initiated in which pollen was mechanically collected in Catamarca Argentina, where jojoba flowers in September, and then applied in commercial fields in Arizona in March the next year. This plan of work was established to ensure that pollen would be available for application when the female plants were receptive in Arizona.

2. Materials and methods

2.1. First year

In September 2002, jojoba pollen was collected in Catamarca Argentina (approximately 28°S latitude 65°W longitude)over a 3-week period from males that had been propagated from seed. Pollen harvest was done with a vacuum system designed for the purpose. The unit consists of a hand wand with mesh end that the operator passes over the surface of the plants. The vacuum source pulled the pollen into a separation chamber where the pollen fell into a plastic bag. After 2–3 h throughout each collection day, the plastic bags were removed from the harvester and placed in a cooler containing ice. At the end of each day, the pollen was screened through window screening, placed in another plastic bag, and then transported to a freezer for storage at −18 °C. A total of 1 kg of pollen was collected.

The pollen was air freighted to Tucson packed on ice, then stored at −30 °C until applied. Two weeks prior to application the pollen was tested for viability by a commercial laboratory using the process employed for olives, pistachios, kiwi, etc. Procedure used in the viability tests included: precondition in an isotonic solution; add fluorescein diacetate; and incubation for 5–10 min. A sample was then withdrawn and viewed under a fluorescent microscope. The pollen grains that fluoresced were counted and the viable grains per gram calculated.

Pollen application was made in the Hyder Valley of Arizona (33°N latitude and 113°W longitude) on 3 March and 26 March 2003. Because the amount of pollen required to provide optimal fruit set was unknown, an application rate was chosen based on previous work with olives (Ayerza and Coates, 2004). The mixture applied contained 12.6 million viable grains/g, giving an application rate of 1.2 billion viable pollen grains per hectare.

The test field was comprised of five rows of female plants between each row of male plants. Row spacing was 4 m. Male plants in this field had been established from seeds, whereas female plants were started from cuttings. The source of the cuttings was unknown. The age of all of the plants was approximately 20 years.

Four replicates, each comprised of the center 3 rows of the five rows of female plants between a single row of male plants, were used for the trials. Within a replicate, female plants were of the same clone. The replicates were separated by at least 20 rows of plants to reduce potential pollen drift effects. Each test plot was 100 m long. The pollen applicator, which is comprised of a hopper, metering screw and small blower, was mounted on an All Terrain Vehicle that moved at 5 kph. Actual application rates were 100 g/ha on 12 March, and 115 g/ha on 26 March 2003.

To determine whether or not the pollen was viable and the pistils were receptive, five branches from different plants within each replicate, but outside the area where pollen was mechanically applied, were selected. On each date, copious amounts of pollen were applied by blowing it from the palm of a hand onto flowers. Branches were tagged so that they could be located and pollination efficacy assessed. On 13 May 2003, flowers that either set or did not set were counted on each set of the hand-pollinated branches. Additionally, 20 branches on both the east and west side of the center treated row of each replicate were selected for assessment and the flowers counted that set and did not set.

2.2. Second year

In September 2003 pollen was collected in Argentina from the same location as the previous year, over a 1-week period. The short collection time was due to unusually hot, dry winds, which reduced pollen production. Because pollen viability had been low the previous year, care was taken during this harvest to ensure that the collection bags were placed in a cooler in the field each hour, rather than the 2–3 h periods used the previous year. Again, at the end of each collection day, the pollen was screened, placed in a plastic bag, and then transported to a freezer for storage. A total of 750 g of pollen was collected. As in the previous year, the pollen was packed on ice and transported via air freight to Tucson, AZ where it was stored at −30 °C until applied the following spring. Samples were sent to a commercial laboratory for pollen viability determination approximately 2 weeks prior to application.

Application took place in the Hyder Valley of Arizona on 16 March 2004 with pollen containing 9.8 million viable grains/g. The viability was much less than that of the pollen applied the year before (12.6 million viable grains/g). Because pollen application the previous year had inconclusive results, the application rate was increased to 11.7 billion viable grains per hectare, approximately 10 times that of the previous year. Only one application was made, as warmer weather during the spring led to a much shorter flowering period than the previous year.

For 2004, a different field in Arizona was used because the field used in 2003 had not been properly maintained and was considered less suitable for test purposes. The field layout, however, was the same with five rows of female plants between a single row of male plants. As in the previous year, males in this field had been established from seeds, whereas the females were started from cuttings of an unknown clone. The age of the plants was again approximately 20 years.

Because the males in the test field produced much more pollen than had been the case the previous year, it was decided to change the plot configuration so that pollen was applied only between one pair of female rows at the plot center and farther away from the males on either side. Two sets of rows were selected for application, again not from adjacent groups of females. The approximately 210 m long rows were divided as follows: (a) the first and last 15 m were excluded to account for end effects; (b) the remainder was divided into six 30 m-long test sections. These were alternately selected for pollen application and left as the control.

For the previous year, pollen collection equipment had been used only on a test basis in Arizona. To evaluate its effectiveness, and provide an estimate of the quantities and quality of pollen that could be collected, trials were conducted over a 10-day period starting on 16 March and ending 25 March 2004. As in Argentina, bags containing pollen were removed hourly from the collector and placed along with frozen blue ice in a cooler. Screening was not necessary in Arizona as the pollen was much cleaner because screen had been attached to the outside of the collection device. Following collection, pollen samples from each day's harvest were sent to a commercial laboratory to determine viability.

On 7 May 2004 flowers that were set and not set were counted on 20 branches from the inside of the female rows that had been treated, as well as from the control sections.

3. Results and discussion

3.1. First year

3.1.1. Pollen collection—Arizona

Pollen collected in 2003 weighed 200 g. Viability of the three samples collected in Arizona was much higher than that of the pollen collected in Argentina, and ranged from a low of 34, to a high of 45 million viable grains/g. It is thought that the major reason for the significantly lower viability of the pollen coming from Argentina in 2002 was due to less frequent emptying of the collection bags in the field, combined with frequent power outages that made storage conditions prior to transport to Arizona unfavorable. During this time period, storage temperatures greater than −30 °C were probably encountered.

3.1.2. Results of the hand pollination trials

The mean number of flowers set, not set, and percent set for the first and second application dates are shown in Table 1. No significant ($P < 0.05$) difference in any of the mean values was detected according to Duncan's multiple range test. These results indicate that application date did not affect pollination, and that the female plants were equally receptive on both dates.

A comparison of the hand treated branches with branches selected from the control plots is also shown in Table 1. Duncan's multiple range test found significant ($P < 0.05$) differences in the number of flowers set and not set between the hand pollinated and the control branches. No significant difference in percent flower set was detected.

Table 1
Jojoba flowers set, not set, and percent set when supplemental pollen from Argentina was applied in Arizona

Treatment	Year	Flowers set	Flowers not set	Percent set
First hand application (3 March)	2003	51.1	7.8	84.3
Second hand application (26 March)	2003	59.9	10.6	85.4
Hand application	2003	55.3 a[a]	9.2 a	84.8
Control	2003	38.8 b	6.0 b	84.4
Machine application	2003	38.9	6.0 b	86.2 a
Control	2003	38.8	7.1 a	84.4 b
Machine application (16 March)	2004	30.8	3.5	90.8
Control	2004	25.6	2.7	89.8

[a] Means within a grouping, within a column, followed by a different letter were significantly different at the $P = 0.05$ level according to Duncan's multiple range test.

3.1.3. Results of the machine pollination trials

Mean number of flowers set, not set and percent set for the treated and untreated rows are listed in Table 1. Duncan's multiple range test found a significant difference in flowers not set and in percent of flowers set between the treated and untreated rows. No difference in flower set was detected. These results indicate that application of pollen did increase percentage set, with the difference arising because of differences in the number of flowers that were not set between the control and treated plots.

3.2. Second year

3.2.1. Pollen collection—Arizona

Pollen was collected between 16 March and 25 March, every day except for 21 and 22 March, days on which extremely hot, dry winds persisted. Daily pollen collection amounts and viability are shown in Table 2. Although quantities collected from day to day did not change significantly, viability dropped nearly 10-fold following days with hot dry winds.

Table 2
Date, amount, and viability of pollen harvested in Arizona in March 2004

Date (March 2004)	Amount (g)	Viability (million grains/g)
16	600	30.7
17	950	36.11
18	990	23.3
19	1400	28.6
20	940	20.3
23	760	4.8
24	840	3.4
25	640	7.8

3.2.2. Results of the machine pollination trials

Mean number of flowers set, not set, and percent set for the treated and control plots are shown in Table 1. No significant ($P < 0.05$) difference in any of these parameters was detected according to Duncan's multiple range test.

The second-year tests did not produce an increase in flower set as in the first year. Even though there was a 10-fold increase in viable pollen grains applied the second year, close proximity of prolific pollen producing males to the females prevented the trial from producing an enhanced flower set.

4. Conclusions

The 2-year study did not provide sufficient data to indicate that supplemental pollination of jojoba in commercial fields could increase yield. Field configuration and timing of release of both pre-existing rows of male plants and supplemental pollen significantly affects the amount of fruit set increase that is possible with application of supplemental pollen. This may be the reason for the difference in the findings observed between years.

A significant finding from this study was the large decrease in pollen viability due to the hot, dry weather that occurred during the time period pollen was produced. Data show that the timing of pollen collection is critical. Unless males are producing viable pollen when the females are receptive, fruit set can be low and explains yield variations found from year to year in commercial fields.

Perhaps supplemental pollination in jojoba could be beneficial. However, more research is needed. Studies to determine optimal time of pollen collection and application are required. In addition, the amount of pollen applied to optimize fruit set needs to be established in order to minimize the cost of pollen collection and application.

Acknowledgments

This project was 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., Buenos Aries, Argentina is also appreciated.

References

Ayerza, R., Coates, W., 2004. Supplemental pollination—increasing olive (*Olea Europaea*) yields in hot, arid environments. Exp. Agric. 40, 481–491.

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 (3), 111–124.

Haffar, I., Al Juburi, H., Ahmed, M.H., 1997. Effect of pollination frequency and pollen concentration on yield and fruit characteristics of mechanically pollinated date palm trees (*Phoenix dactylifera* var Khalas). J. Agric. Eng. Res. 68, 11–14.

Sibbett, G.S., Freeman, M., Ferguson, L., Polito, V.S., 1992. Effect of topically applied 'Sevillano' pollen on normal-seeded and parthenocarpic "shotberry" fruit set of 'Manzanillo' olive. Hort. Technol. 2 (2), 228–230.

Tobares, L., Frati, M., Guzman, C., Maestri, D., 2004. Agronomical and chemical traits as descriptors for discrimination and selection of jojoba (*Simmondsia chinensis*) clones. Ind. Crops Prod. 19, 107–111.

Vaknin, Y., Gan-Mor, S., Bechar, A., Ronen, B., Eisikowitch, D., 2001. Improving pollination of almond (*Amygdalus communis* L., Rosaceae) using electrostatic techniques. J. Hort. Sci. Biotechnol. 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 Breed. 121, 451–455.