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Evaluation of jojoba germplasm in different environments

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Foreword

Jojoba is a crop which appears to have a role as a diversification option for farmers in the drier areas of Australia.

A small number of growers are now harvesting this desert plant with potential for both domestic and export uses. Primarily it is used as an oil (though scientifically it is a wax) in cosmetics and other industries.

The project was the second stage of the National Improvement Program for Jojoba.

This project was supported by RIRDC with the objective of isolating the most productive lines of jojoba under changing climatic conditions and the influence of deferring degrees of chill.

The report aims to evaluate the response of jojoba germplasm in different environments. The aims of this project were to:

- evaluate the response of flowering and seeding of a diverse, but known, range of jojoba germplasm to changes in climate across Australia
- provide benchmarks to assist researchers and growers in the selection of new varieties as well as give confidence in recommending where new selections are best suited.

This report, an addition to RIRDC's diverse range of over 1500 research publications, forms part of our NPP R&D program, which aims to facilitate the development of new industries based on plants or plant products that have commercial potential for Australia.

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Peter O'Brien
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Field monitoring and plant management of each site over the past six years has been undertaken by Judy and Kim Felton-Taylor, Goondiwindi; Stephen Uphill, Wirrinya; Catherine Beazley, Hillston; Rod Fenton, Kerang and Beverley and Bert van der Brink, Nildottie. Without their input this project would not have been possible. Their contributions are gratefully acknowledged.

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Executive Summary

Most of the initial work on selecting suitable varieties of jojoba in Australia was centred on work conducted at Condobolin in central-west NSW. The selection process relied on varieties responding to the prevailing climatic conditions by initiating flowering and seeding at the most appropriate time – in this case, after the threat of severe frosts had passed. Extension of this knowledge in recommending the varieties relied on computer models matching chill requirement to the climate of a particular area, but this has not been validated by field testing.

This project aimed to observe how a number of lines of jojoba with known, but different chill requirement respond under changing climatic conditions. Trial sites were established at five locations in south-eastern Australia from southern Queensland southward to central NSW, northern Victoria and eastern South Australia. These sites were planted in commercial plantations and managed by cooperating jojoba growers who later collected all the flowering data. After an initial establishment period of three years, the trial ran for three years commencing in 2002. Each year branches of plants were tagged at the onset of winter and flowering monitored during the winter-spring period. Seed set was also recorded in late spring to obtain a measure of pollination.

From central NSW southward and westward the response of the various lines has been as predicted, and the current selected varieties appear well suited to much of south-eastern Australia recommended for jojoba growing. However, there are some concerns in the region to the north. Shorter and milder winters here provide a much narrower window of opportunity for chill accumulation to occur as well as for plant reserves to accumulate. The task of selecting more appropriate varieties will be difficult as low-chill plants flower too early and are affected by frost while high-chill plants may not receive sufficient chill accumulation by the end of winter to break bud dormancy.

This research recommends that:

1. Additional data is required to have greater confidence in the results. There is already agreement among the co-operators and the Australian Jojoba Industry Association that the data collection continue for at least another year.
2. Ongoing new variety selection work continues using the current selection parameters, bearing in mind that mid-chill lines may be better placed in the northern parts of the current growing area.

1. Introduction

The initial work of selecting suitable Australian varieties of jojoba occurred between 1981 and 1990 and was centred at Condobolin in central-west NSW. A number of varieties that gave consistent yields were selected as a result of this work. Jojoba is a warm season grower, commencing growth in spring (when mean daily temperatures exceed 12.5 ºC) after a winter dormant period of about three months. As the plant grows, new flower buds are produced terminally with further stem growth initiated from one of the axillary buds. Most jojoba plants produce a flower bud on every other node. Growth continues until the onset of winter dormancy the following year, if sufficient soil moisture is present. Jojoba responds to drought or cool temperature induced dormancy by ceasing growth and accumulating reserves in the leaf for later growth and reproduction (Milthorpe and Khu 1997). In our climate, rainfed jojoba usually accumulates starch during autumn, if it is dry, and then during winter when mean daily temperatures fall below 12.5 ^{o}C. Continual irrigation in autumn that promotes growth restricts jojoba's ability to accumulate these reserves.

All buds then remain dormant until a trigger allows their development to flowers. This is believed to be a chill requirement. Plants with a low-chill requirement may flower at anytime (and sometimes several times) of the year, while those with a high-chill requirement do not break dormancy until well into winter when cold temperatures prevent further development until spring. It is believed that maximum chill accumulation takes place when the temperature is at 18ºC and ceases below about 10ºC. Chill reversal appears to occur when temperatures exceed 24ºC, allowing the plant to avoid short false starts to the chill accumulation process. Chill requirements for many lines were determined in previous studies at Condobolin (Ferriere *et al,* 1989). This was determined by taking branch cuttings periodically from plants and forcing them in a growth cabinet set at 24ºC and recording when 50% or more buds opened. If this occurred in 15 days the 'set-to-open' (STO) condition or dormancy break was achieved. From this work a number of Lines, with known chill requirement, were able to be selected and used for this project.

Most plants from the wild population of jojoba (based on previous research at Condobolin) have reached STO condition by early- to mid-June each year. Frosts of greater severity than -2.5ºC (screen temperature) are detrimental to flowers and flower buds that are developing, following dormancy break. Consequently, a spell of warm weather in June promotes premature flowering or bud development increasing the likelihood of bud or flower damage later in winter. Prolonged severe frosts (≤ -5ºC) can kill all unhardened growth (stems, leaves and buds), but these conditions prevail infrequently and there is little that can be done to prevent it.

Natural stands of jojoba in Arizona are predominately restricted to hillsides where cold air drainage during winter offers them some protection from severe frosts and allows infrequent seed set, but sufficient for the plants to persist. Commercial production has moved the plants to the valley floors to allow irrigation, however this increases the threat of frost damage. The extreme diurnal temperature range (-10^{o}C to +20^{o}C) during the winter months on the valley floors promotes bud development following chill fulfilment (STO) and frost damage is very common (Milthorpe 1992). Growers obtain some protection by severely drought stressing plants in the autumn-winter period to retard growth and development. In Australia, we have elected to rely on the generic ability of plants to respond to the climate and have made our selections accordingly.

Pollination studies (unpublished data) have shown that there is a relatively narrow window of temperatures (24ºC ± 3ºC) where pollen tube growth is rapid and fertilisation of the ovary effective to achieve good seed set. At temperatures below 21ºC pollen tube elongation rates are significantly curtailed and levels of seed set are not only reduced, but frequency of twinning is markedly increased. This has been clearly demonstrated in glasshouse grown plants at Condobolin (unpublished data). Also in a field site in South Australia, near Port Pirie, where a maritime climate prevails with winter temperatures of 18-20ºC during July, permitting abundant early flowering but seed set is usually very low. Consequently, it is important to maximise flowering when day temperatures are around 24ºC. At Condobolin, this generally does not occur until the last week of August or early September.

Subsequent to the selection of three varieties at Condobolin, commercial plantations using these varieties were established throughout much of the cereal growing areas of the mainland and beyond. There is a gradual shift in climatic conditions with increasing distance from Condobolin. To the north and west winters are milder and shorter (Table 1) and there is a shift in seasonal rainfall to greater summer incidence. Plants with high-chill may not achieve STO if winters are mild and short. Southward and westward spring temperatures are cooler and the incidence of winter and spring rainfall increases.

	Jul	Aug	Sep	Oct
Goondiwindi	11.5	13.3	16.5	20.5
Hillston	9.3	11.3	13.8	17.5
Nildottie	9	10.6	12.7	15.8
Kerang	9.9	10.6	12.7	16.2
Wirrinya	8.1	9.7	12.2	16.1
Condobolin	8.4	10.2	12.8	17.2

Table 1. Mean daily temperatures (^{o}C) for six locations in south-eastern Australia from July to October. *(Bureau of Meteorology)*

This study was established at five locations across south-east Australia following concern about the impact of these gradual climatic changes on the performance of our selected jojoba varieties. Sites on commercial plantations were selected at Goondiwindi, Hillston, Wirrinya, Kerang and Nildottie to capture the range of climatic shifts (Table 1).

The temperature profiles for Kerang, Nildottie and Wirrinya are slightly cooler in spring than Condobolin while Hillston is slightly warmer. The season at Goondiwindi is three weeks to a month earlier than at the other sites.

Another two sites were planned for regional Western Australia, however these plants did not reach sufficient size to provide reliable data so were not included in the trial.

2. Objectives

These were to:

- evaluate the response of flowering and seeding of a diverse, but known, range of jojoba germplasm to changes in climate across Australia
- provide benchmarks to assist researchers and growers in the selection of new varieties as well as give confidence in recommending where new selections are best suited.

3. Methodology

Trials were established at five sites in south-east Australia to record flowering patterns of selected lines of jojoba with known chill requirements (Ferriere *et al*, 1989). Each trial consisted of a randomised block design of eight lines of plants with three replicates. There were three plants of each line at each planting site. The initial plantings were made in 1999 to allow three years growth to achieve reasonable plant size prior to the commencement of data collection for this project. The trials were laid out in commercial plantations and received normal management with regard to weed control, fertiliser and water application and any other cultural needs.

Data collection for these trials commenced in the winter of 2002. Each year, branches of each plant were tagged after the onset of winter dormancy (usually early July) and the number of nodes and flower buds recorded. Branches with 20 or more nodes of first year wood were selected. Landholders were then responsible for monitoring flowering (the number of opened flower buds) over the winter-spring period. Periodic observations were made until flowering commenced, then regularly made on a 3-5 day basis until the completion of flowering. A further recording was made about six weeks after the completion of flowering to record the number of flowers that set fruit.

Data from each site was then collected and collated. The female lines were coded according to their chill requirements, for example, Line 102 requires least chill and Line 106 the greatest chill accumulation. For the male lines, chill requirement was the reverse with Line 201 requiring greatest chill and Line 203 needing least. Insufficient clonal material was available to meet the needs at each location and when this occurred another Line with similar chill requirement was substituted. At Kerang, Line 101 was used in place of Line 102, which was common to the other four locations.

Some difficulties were experienced in obtaining full sets of data in some years due to circumstances beyond the control of the co-operators, however sufficient data has been collected to see trends in behavioural patterns of the different germplasm used.

4. Results

Plant survival has been good at all sites despite drought prevailing for most of the period and the inability to irrigate at most sites. However, at some sites plants were not as large as anticipated, but still sufficiently large to allow tagging.

Buds were deemed to be open when the styles of the female flowers were visible to the naked eye and when pollen could be tapped from the male flowers. In the case of males, if one flower of the inflorescence had opened then that cluster was deemed to be in flower.

Repetition in location, year and Line may make interpretation of the Figures difficult. To assist in recognition, the legends for each Figure have been coded to show in order:

- Site G = Goondiwindi; H = Hillston; K = Kerang; N = Nildottie and W = Wirrinya
- Year 02 = 2002; 03 = 2003 and 04 = 2004
- Line females: Lines 101 to 106
  males: Lines 201 to 203

As an example, a legend coded H02102 would be data from Hillston in 2002 for female Line 102.

4.1 Flowering

The number of opened buds were recorded against the day number after July 1st each year and then graphed as a percentage of opened flower buds for each Line against time. Flowering was deemed to be at a maximum when 50% or more of buds are open, or where less than 50% of buds opened, maximum flowering is when the slope of the graph is steepest. In this study it was not possible to determine the exact reason why only a low percentage of buds open in some instances. There are four reasons why buds fail to open. These are because buds:

- receive sufficient chill and start development, but are frosted prior to opening
- fail to receive sufficient chill
- are killed by extreme frosts (≤ -5ºC), and these are mainly the tip buds, or
- die prematurely due to crushing of the vascular tissue. This only applies to buds located in the fork of a branch.

Some determination of cause of death can be made by dissecting the buds and use of a microscope, but this was not feasible in these studies.

There was great variation in peak flowering time between years at each site and this is due largely to seasonal climate differences, but there was reasonable consistency in phase development between lines each year. This is best illustrated by the three lines of males at Hillston (Figure1).

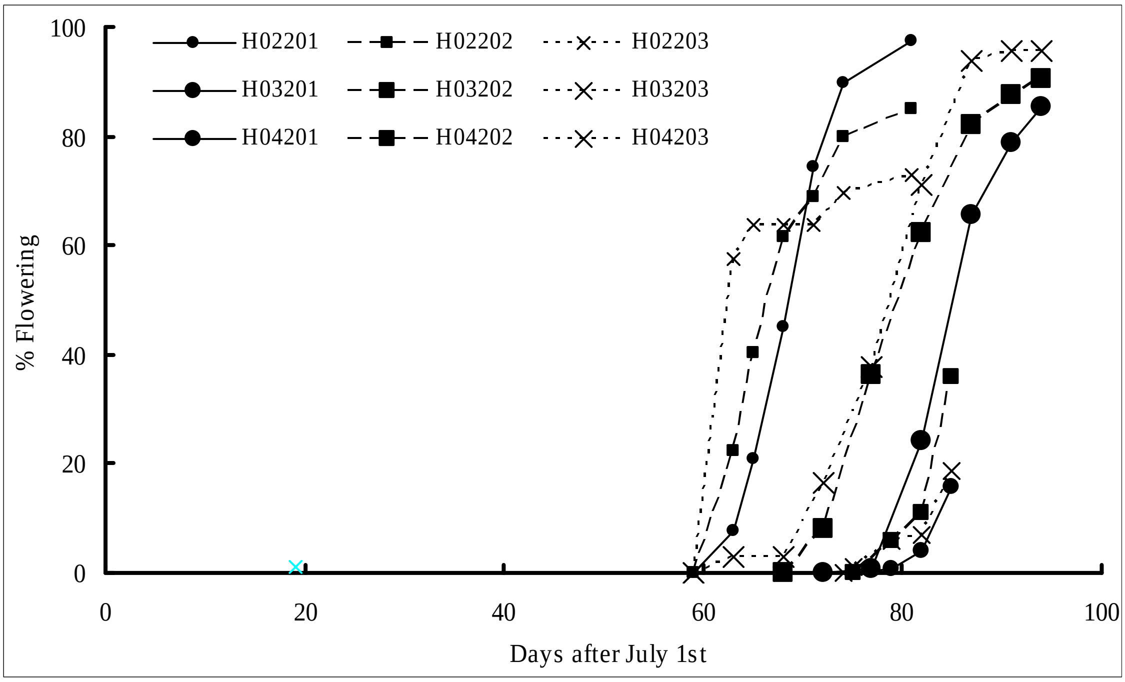

Figure 1. Flowering profiles for three male lines at Hillston for each of three years

Here maximum flowering (50% of buds opened) in 2002 occurred around Day 65 and Line 201 (H02201), the line with highest chill requirement, started last (Day 68) but almost all buds opened compared with the earliest male Line 203 (H02203), which started earliest (Day 59) but only about 75% buds opened. Flowering in 2003 was severely affected by frosts and it was not only late (post Day 85) but less than 50% buds opened for any line. The timing of flowering in 2004 was intermediate between the other two years and a high percentage of buds opened.

4.2 Selected locations

The pattern of flowering was more or less as expected at most locations, however the plants at Goondiwindi behaved differently compared to those at other sites. Some of the major differences and similarities are discussed.

4.2.1 Goondiwindi

Female plants

The flowering profiles for the female lines with the lowest (102) and highest (106) chill requirement are markedly different (Figure 2). Line 102 invariably received sufficient chill accumulation in autumn-early winter and commenced flowering well before the onset of winter dormancy, consequently only a low percentage of buds opened in the spring period when temperatures are best for pollination. In contrast, Line 106 did not commence flowering until the end of August, but only a low percentage of flower buds opened in any year. It is uncertain why there was such a low flowering rate and may be due to lack of chill accumulation occurring. The greater incidence of summer and autumn rainfall at this northern site coupled with a shorter, milder winter dormancy period means there is less time when plants are dormant and able to accumulate starch reserves. It is not known how significant this is on the subsequent reproductive phase of the plants.

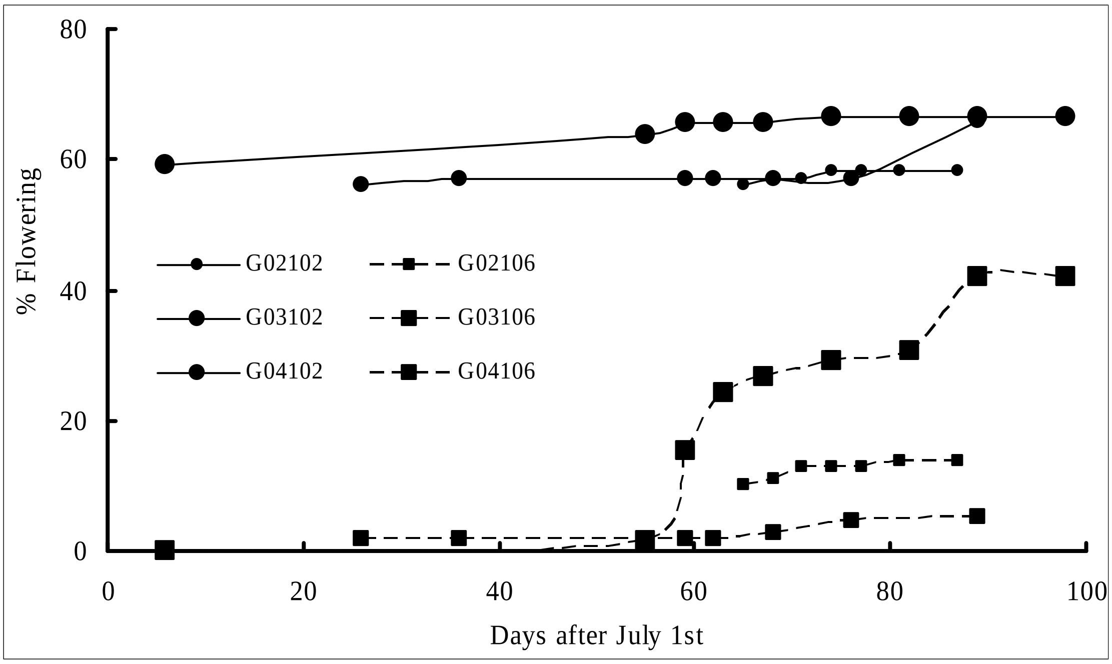

Figure 2. Flowering profiles for low-chill Line 102 and a high-chill Line 106 at Goondiwindi over three flowering events.

The flowering profiles for intermediate Line 104 shows a mixed response over the three-year period (Figure 3). In 2002 and 2003 flowering was poor and protracted due to sufficiently mild climatic conditions to allow development. In 2004 there was a short flowering burst at the end of August (Day 60) followed by a major flowering at Day 82.

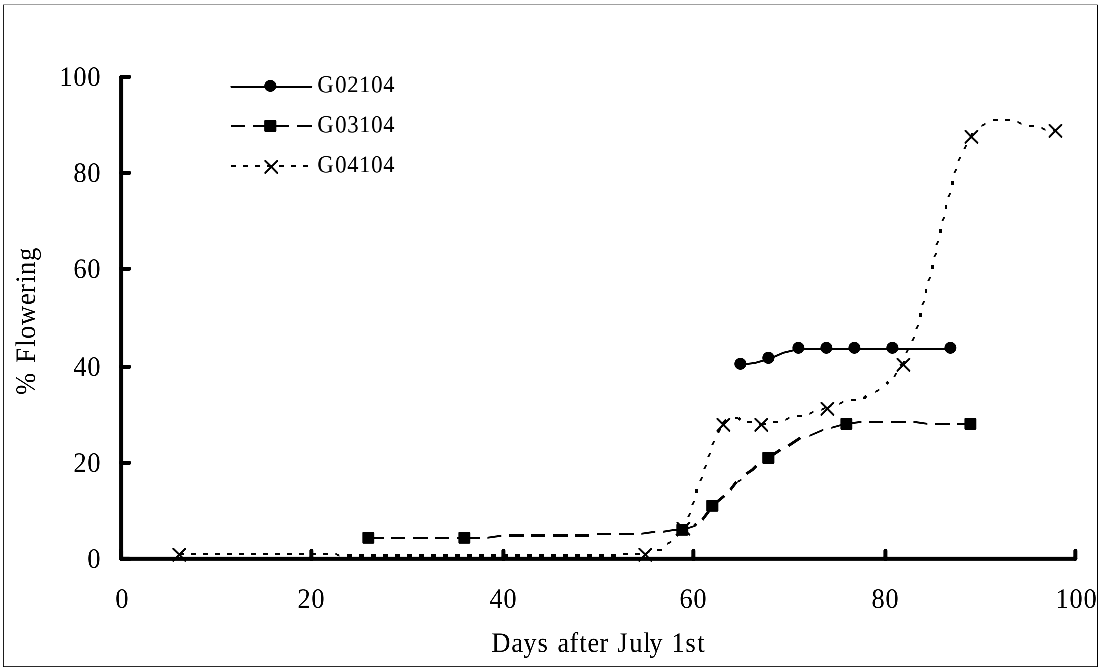

Figure 3. Flowering profiles for Line 104 (intermediate chill requirement) at Goondiwindi for three separate years (2002-2004 inclusive).

Male plants

The males lines at Goondiwindi performed more consistently with 201 very contracted in its behaviour compared to 203 which had a protracted flowering pattern similar to the low-chill female lines (Figure 4).

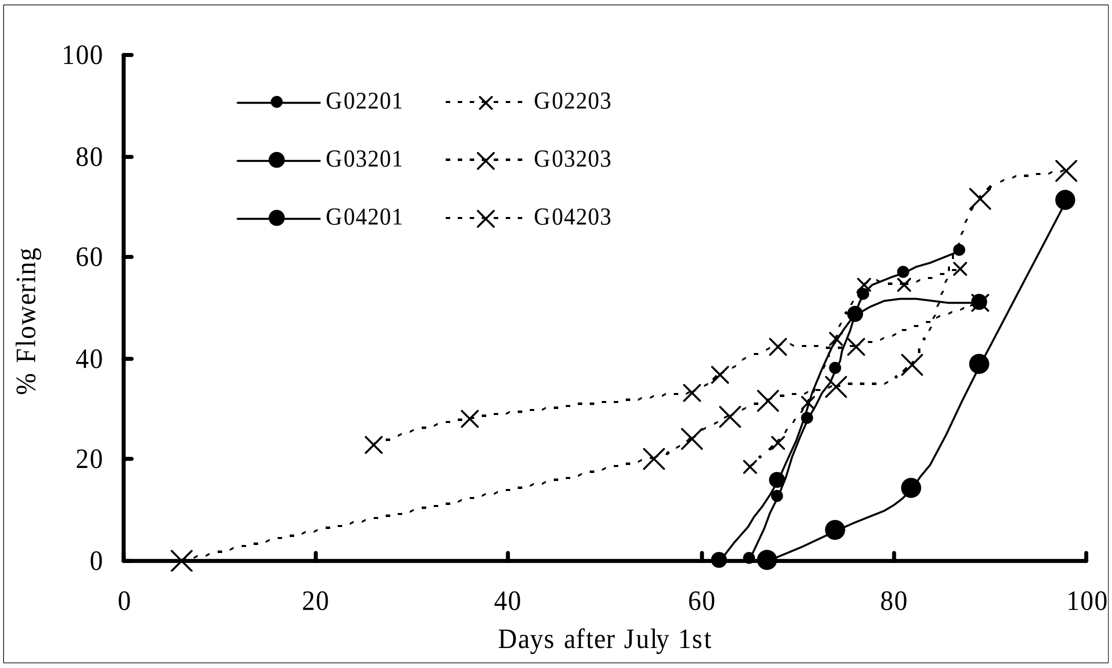

Figure 4. Flowering profiles for two male lines (201and 203) at Goondiwindi over three flowering periods.

4.2.2 Hillston

The low-chill Line 102 at Hillston also demonstrated its ability to flower early if suitable conditions prevailed. Little flowering took place until August, but a substantial percentage of buds had opened by the end of August in each of the three years with few buds opening subsequently (Figure 5). August frosts would kill these buds or flowers, but in a mild year these plants would set fruit. The flowering pattern of this line at Hillston differs from that at Goondiwindi (see Figure 2) in that the majority of the buds had opened well before July 1 at Goondiwindi and any critical frost during winter would kill the buds/flowers and seriously reduce yield potential.

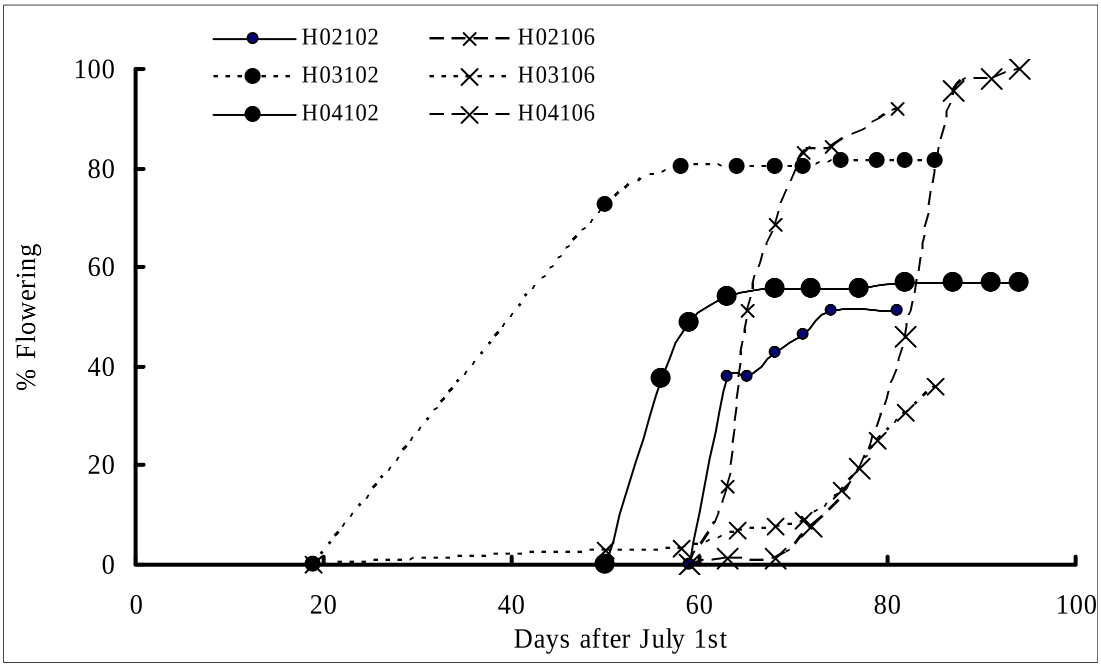

Figure 5. Flowering profiles for Line 102 (low-chill) and Line 106 (high-chill) at Hillston over three flowering events.

Line 106 (high chill) didn't flower until after the end of August (post Day 60) in any year at Hillston and, except for 2003, there were a high percentage of buds that opened.

At other locations Line 106 always flowered after the end of August (Day 60). Only data for 2004 is shown (Figure 6).

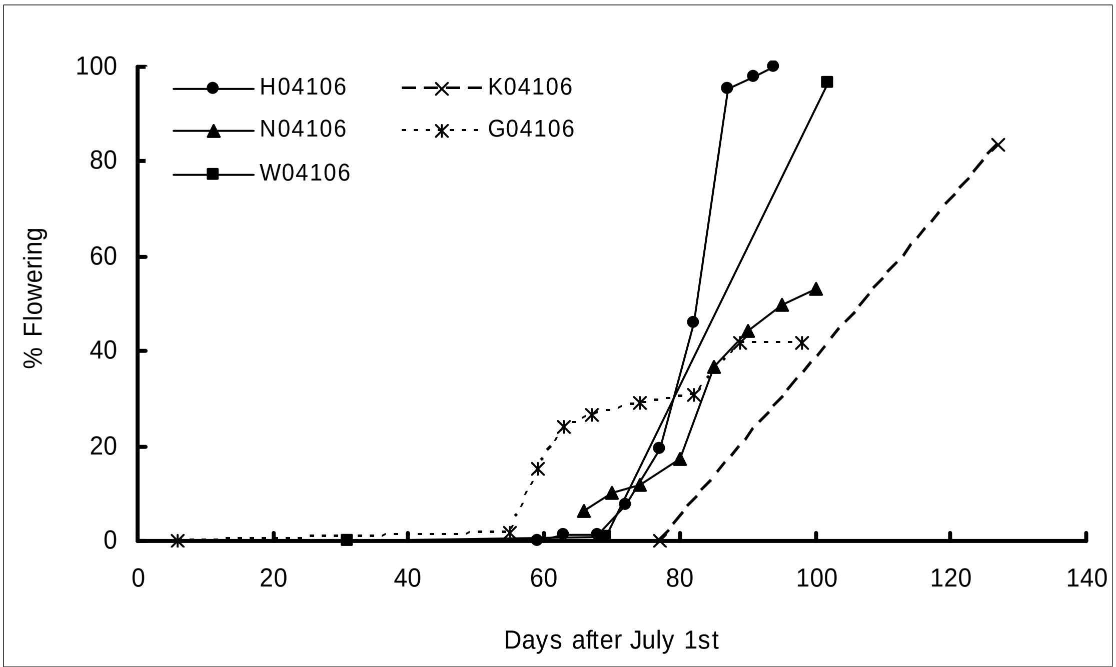

Figure 6. Flowering profiles for high-chill Line (106) at five sites in 2004.

4.2.3 Other sites

The flowering profiles at the other sites tended to be closely aligned with what happened at Hillston, but there are a few exceptions. At Wirrinya, Line 102 (low-chill) commenced flowering early July, paused and then had another flush of opened buds in September, otherwise the Wirrinya site responded with flowering occurring with the onset of warm weather each spring. The plants at Nildottie also had a condensed flowering period commencing with the warm weather of spring, however in 2004 the number of buds in Line 106 that opened was inexplicably lower than expected (Figure 6).

4.3 Summary of flowering profiles

Time of flowering of jojoba is important not only to avoid the threat of frost but also to ensure effective pollination and good seed set. For most of the area where jojoba is grown it is important that flowering does not occur before the end of August. To illustrate the importance of this, the data was reworked to show the percent flowers that opened on or after the end of August (Day 60) averaged over the three-year period (Table 2).

	Females					Males		
	Line 102	Line 103	Line 104	Line 105	Line 106	Line 203	Line 202	Line 201
Goondiwindi	7	6	30	22	13	37	18	63
Hillston	7	42	40	57	76	60	68	68
Nildottie	10	34	39	60	38	53	62	63
Kerang	40	34	75	63	82	17	80	40
Wirrinya	42	71	73	55	87	5	28	60

Table 2. Average percentage of buds opening on, or after, August 30 each year

This Table shows the importance of high-chill as there is a general increase in the percentage of buds opened after the end of August with increased chill required at each location. At Goondiwindi, there is an apparent decline in the number of buds opening in the high-chill lines and also at Nildottie, for Line 106. The males generally behaved as expected except for Line 201 at Kerang, where low flowering occurred.

4.4 Seed set

Seed set is determined by the number of flowers opening and the ability of pollen to fertilise the receptive flowers, less the impact of frost if flowering occurred prior to the end of the frost period. Average seed set has been calculated for each of the five female lines at each location by dividing the number of fruits present by the number of recorded opened flowers and expressing the result as a percentage (Table3).

	Line 102	Line 103	Line 104	Line 105	Line 106
Goondiwindi	3	9	43	49	46
Hillston	15	45	46	62	62
Nildottie	46	55	72	71	56
Kerang	46*	32	55	43	56
Wirrinya	59	39	48	47	60
* Line 101 used at this site					

Table 3. Average seed set over a three-year period for each of five lines at five locations.

At Goondiwindi and Hillston there is increased effectiveness in seed set with increasing chill requirement, however at the other locations seed set was more uniform across all lines, highlighting the importance of the winter dormancy acting as a clock by restricting flowering until the onset of warm spring temperatures when growth and development re-commences.

5. Discussion and implications

The response of the different Lines of jojoba was predictable particularly to the south of Condobolin, where the response at all locations was similar. The Goondiwindi plants behaved quite differently and this will be discussed separately.

Cool temperatures and the onset of winter dormancy acts as a clock in shutting down plants in winter and allow them to accumulate reserves as well as reach STO. Variations in seasonal temperature patterns result in a shift from year to year when plants flower, but the response of the different lines remains in phase irrespective of whether flowering is early or late. The dry conditions that have prevailed prior to and during the trial has resulted in smaller plants than expected and this may have influenced the behaviour of some lines.

In some years, Lines with low-chill requirement flower prior to the onset of winter dormancy or commence development and they ultimately fail to set viable seed.

Lines with high-chill requirement behaved consistently at all locations, however there were a couple of instances where the percentage of buds opening was lower than expected for some unclear reason, but possibly due to small size. Line 106 is naturally dwarfed compared to the other lines. It is known that back radiation from the soil interferes with the behaviour of small plants.

Levels of pollination of flowers were reasonably consistent, even if lower than expected, at these southern four locations, again reflecting the ability of plants to respond to the warmer conditions following the break of winter dormancy.

At Goondiwindi the winters appear not to act as the clock in shutting down plants to the same degree as happens further south and growth may occur throughout winter or winter dormancy is very short. Low- and mid-chill Lines consistently flower early and resultant seed set is poor. Lines with high-chill requirement appear to be affected by their inability to reach STO prior to the onset of spring conditions, whereas mid-lines fared better. The shorter and milder winter conditions that prevail result in a much narrower temperature window for plants to respond and this makes it more difficult to make suitable selections, especially given the large year by year seasonal variation that is experienced. This site, while not as extreme as that experienced in Arizona has temperature regimes with very low margins in which to select suitable Lines.

Generally most of the region south and west from central NSW appears to give a similar response pattern to that at Condobolin and the recommended varieties are well suited to here. However further north, there is concern that the selected variety with the highest chill requirement may not best suited to those conditions.

6. Recommendations

There are two recommendations that come from this work. These are:

- that additional data is required to have greater confidence in the results. There is already agreement among the co-operators and the Australian Jojoba Industry Association that the data collection continue for at least another year.
- that ongoing new variety selection work continues using the current selection parameters, bearing in mind that mid-chill lines may be better placed in the northern parts of the current growing area.

7. Glossary

Germplasm: The unique units of heredity (chromosomes) contained by that organism.

Inflorescence: A cluster of buds or flowers supported by one main stem.

8. References

----- (1988). *Climatic Averages Australia*. Bureau of Meteorology. Australian Government Publishing Service, Canberra.

----- (1990). Jojoba *(Simmondsia chinensis*) *Plant Varieties Journal*. Australian Government Publishing Service, Canberra. **3** (1), 14-6.

----- (1991). Jojoba (*Simmondsia chinensis*). *Plant Varieties Journal*. Australian Government Publishing Service, Canberra. **4** (4), 19.

Dunstone, RL and Milthorpe, PL (1995). A screening technique for the rapid selection of suitable jojoba cultivars. Final report to the Rural Industries Research and Development Corporation (DAN 65A)

Ferriere, J, Milthorpe, PL and Dunstone, RL. (1989). Variability in chilling requirements for the breaking of flower bud dormancy in jojoba (*Simmondsia chinensis* [Link] Schneider) *Journal of Horticultural Science*. 60, 901-9.

Milthorpe, PL (1998). Jojoba *In* The new rural industries. (Ed K.W. Hyde) RIRDC, Canberra. 384-9.

Milthorpe, PL and Dunstone, RL. (1996). Jojoba Agfact P5.2.8 second edition. NSW Agriculture.