The search for alternative safflower (*Carthamus tinctorius* L.) cultivars adapted to southeastern Australia with improved marketability

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Abstract

The Australian safflower industry is based on a few cultivars that are not adapted to all environments or targeted at specific markets such as high linoleic oil, high oleic oil or birdseed. To address this, up to 13 cultivars/breeding lines from United States, Canada, India and Australia were evaluated at five field sites in contrasting environments across southeastern Australia during the 2001/02 growing season. Two core sites were established near Horsham, Victoria, one being rainfed and the other receiving 200 mm of irrigation water before sowing (pre-watered). Sister sites were established at Frances and Glenroy in South Australia (each site had two times of sowing), and Cressy in Tasmania. Depending on the cultivar at the pre-watered site, flowering commenced 133 to 144 days after sowing (DAS) with the standard Australian cultivar, Sironaria, flowering 136 DAS. Seed yields varied between sites with no single cultivar preforming the highest at each of the sites. Of the 7 experiments, the highest yields were achieved at the pre-watered site (3.42 to 4.15 t/ha; Sironaria = 3.42 t/ha). The lowest yields occurred at the rainfed site near Horsham (0.18 to 0.71 t/ha; Sironaria = 0.43 t/ha) with the remaining experiments producing intermediate yields. Although Sironaria performed well in both times of sowing at Frances, different cultivars produced significantly more seed at the remaining 4 field sites. Compared to Sironaria, some of the other cultivars not only had higher oil contents, but may also be better tailored to existing and potential new markets, e.g. S6005 for oleic oil markets.

Key Words

Safflower, cultivar, yield, markets, oil quality

Introduction

Safflower production in Australia commenced in the 1950's with a disease prone cultivar (Gila) that was introduced from Arizona. The CSIRO commenced a safflower breeding program in 1975 and released Sironaria with good disease resistance in 1987. Sironaria, a birdseed/linoleic oil cultivar, has become the most widely grown cultivar in Australia. Since the CSIRO program ceased, Australia has not attempted to breed new safflower cultivars and few cultivars have been imported from overseas. However, other countries have continued to develop cultivars focusing on increased yields, improved oil characteristics or birdseed qualities with increased disease resistance. Sironaria is white hulled and predominately sold to volatile birdseed markets however its oil type is not suitable for expanding oleic oil markets. Oleic safflower oil is attractive to food industries due to its mono-unsaturation, high quality and tolerance to high temperatures. Safflower cultivars with a striped or coloured hull are not desired by the birdseed industry. With these issues in mind, up to thirteen cultivars/breeding lines from USA, Canada, India and Australia were evaluated at five field sites in contrasting environments across southeastern Australia during the 2001/02 growing season.

Methods

Two core sites were established near Horsham, Victoria, one being rainfed (HRF) and the other being pre-watered with 200mm of irrigation water before sowing (HPW). Sister sites were established at Frances (FR) and Glenroy (GL) in South Australia, and Cressy (CR) in Tasmania (Table 1). The FR and GL sites both had two times of sowing (TOS), TOS1 and TOS2. Seeding rates were adjusted for seed weight and germination to give a target density of 40 plants/m^2. All sites received trifluralin and adequate amounts of fertiliser at sowing. A summary of experimental design and management practices is given in Table 1 and further details are available from authors.

Sironaria was used as the control cultivar at all sites and the number of other cultivars varied between sites due to limited seed stocks. The oleic cultivars tested were S6005, Saffola 555 and UC_1 with the remaining cultivars having a linoleic oil type. Saffola 517 and S501 are linoleic oil seed types and Saffire is a dedicated birdseed type. The remaining cultivars can be considered to be dual purpose or experimental, *i.e.* linoleic oil or birdseed. Seed yield was determined at all sites and further measurements at the core sites included phenology, water use (gravimetric) and oil quality. The seed yields presented here were derived from header samples and adjusted to 8 % moisture.

Table 1: Site and management summary for the 7 safflower cultivar experiments.

Management	HRF	HPW	FRTOS 1	FRTOS2	GLTOS 1	GLTOS 2	CR
Avg. ann. rainfall (mm)	420	420	525	525	585	585	635
Soil pH $_{(CaCl2)}$	7.5	6.3	5.5	5.5	7.2	7.2	4.0
Soil type	Grey cracking clay	Grey cracking clay	Heavy clay loam	Heavy clay loam	Heavy clay loam	Heavy clay loam	Alluvial sand
Plot size (m)	10 ? 3.4	10 ? 3.4	8 ? 1.2	8 ? 1.2	8 ? 1.2	8 ? 1.2	8 ? 1.2
Replicates/design*	4 / RBD	4 / RBD	4 / RBD	4 / RBD	4 / RBD	4 / RBD	3 / RBD
Sowing date	16 Aug 01	16 Aug 01	6 Sept 01	4 Oct 01	20 Sept 01	16 Oct 01	24 Oct 01
Harvest date	27 Feb 02	27 Feb 02	2 April 02	2 April 02	3 April 02	3 April 02	1 May 02

* Randomised Block Design

Results

The Horsham sites experienced an unusually dry growing season with a long, cool spring. Total soil water to 2 m depth at sowing was 822 and 670 mm for the HPW and HRF sites, respectively. At these sites, 197 (HRF) and 201 (HPW) mm of rain fell between sowing and maturity. Rainfall from sowing to maturity at the first sowing at FR and GL was 189 mm at each site, while the rainfall for the second sowing was 116 mm (FRTOS2) and 125 mm (GLTOS2). Conditions were cooler than usual throughout the growing season. The season at CR was also similar to most of southern Australia, being much cooler than normal with 319 mm of rainfall falling between sowing and maturity. Generally, all sites established well, although FRTOS1 suffered from heavy rain one day after sowing. Plant establishment at FR was slow and initially patchy, however the final plant stand was adequate for maximum yield. Establishment at CR was satisfactory, but early growth was inhibited by weeds, which were subsequently controlled with herbicide (metsulfuron).

120045 was the first cultivar to flower at HRF, 123 days after sowing (DAS) and at HPW 132 DAS. Sironaria flowered 127 and 136 DAS at HRF and HPW, respectively. The last cultivar (120043) commenced flowering 132 DAS (HRF) and 144 DAS (HPW). The sequence of physiological maturity was similar to that of flowering and occurred between 158 and 164 DAS at HRF, and 170 and 180 DAS at HPW. Sironaria matured 163 (HRF) and 172 (HPW) DAS, indicating earlier and later maturing cultivars exist along with the Australian standard cultivar (Sironaria).

Seed yields varied extensively between sites (Table 2) with the upper and lower extremes occurring in paddocks with contrasting amounts of stored soil water at the same location (Horsham). The mean yield at the HRF site was 0.37 t/ha compared to 3.75 t/ha at the HPW site. The other sites had intermediate yields, this may be at least partly related to available water. There was little difference between sowing times at Frances with mean yields of 1.51 and 1.68 t/ha, possibly due to the patchy early establishment at FRTOS1. At Glenroy, there was a considerable yield penalty for delaying sowing from September 20 (1.68 t/ha) until October 16 (1.24 t/ha). This trend was consistent for all cultivars. Cressy produced the greatest range of yields between cultivars (0.39 t/ha to 2.29 t/ha). This variation could have been influenced by the weed burden at this site.

Sironaria produced significantly more seed than all other cultivars at FRTOS1. However at FRTOS2 Sironaria yields were not significantly different to the 6 highest yielding cultivars. At all other sites at least one other cultivar produced significantly more seed than Sironaria. 120045 was the earliest maturing cultivar and produced more seed than all other cultivars at HRF. It had similar yields to the highest yielding cultivars at FRTOS1, FRTOS2 and GLTOS1, but performed poorly at CR. The longest season cultivar (120043), also performed poorly at CR, but yields were similar to Sironaria at HRF and HPW. The oleic cultivar S6005, performed well at all sites except HRF, where it yielded the lowest. Lesaf 175 performed poorly at all sites. Overall, no single cultivar achieved the highest yield at all sites, indicating that different cultivars are required to maximise yields in different environments.

Table 2: Safflower seed yields (t/ha) for all 7 experiments.

Cultivar	HRF	HPW	FRTOS 1	FRTOS 2	GLTOS 1	GLTOS 2	CR
Lesaf 175	0.21 ^{a}	3.61 ^{ab}	1.15 ^{a}	1.19 ^{a}	0.78 ^{a}	0.70 ^{a}	0.39 ^{a}
Saffire	0.42 ^{cde}	3.61 ^{ab}	1.52 ^{cd}	1.57 ^{c}	1.68 ^{b}	1.24 ^{b}	1.09 ^{abc}
UC_1	-	3.42 ^{a}	-	-	-	-	-
Sironaria	*0.43* ^{cde}	*3.42* ^{a}	*1.75* ^{d}	*1.57* ^{c}	*1.70* ^{b}	*1.26* ^{b}	*1.12* ^{abc}
120043	0.38 ^{bcde}	3.63 ^{ab}	-	-	-	-	1.59 ^{bcde}
120045	0.71 ^{f}	3.71 ^{ab}	1.46 ^{bc}	1.63 ^{c}	1.85 ^{bc}	1.26 ^{b}	1.02 ^{abc}

S501	0.26 ^{abc}	3.71 ^{ab}	1.48 ^{bc}	1.49 ^{bc}	1.82 ^{bc}	1.42 ^{bc}	2.29 ^{e}
Saffola 517	0.34 ^{abcd}	3.88 ^{bc}	1.27 ^{ab}	1.53 ^{bc}	1.72 ^{bc}	1.23 ^{b}	1.79 ^{cde}
AC Stirling	0.47 ^{e}	3.92 ^{bc}	1.49 ^{bc}	1.66 ^{c}	1.75 ^{bc}	1.49 ^{c}	1.05 ^{abc}
Gila	0.43 ^{de}	3.95 ^{bc}	-	-	-	-	1.18 ^{abcd}
S6005	0.18 ^{a}	3.97 ^{bc}	1.42 ^{bc}	1.59 ^{c}	1.87 ^{bc}	1.34 ^{bc}	2.05 ^{de}
Saffola 555	0.24 ^{ab}	4.15 ^{c}	1.44 ^{bc}	1.35 ^{ab}	1.96 ^{c}	1.23 ^{b}	0.85 ^{ab}
CO 1	-	-	-	-	-	-	1.46 ^{bcde}
LSD (5%)	*0.171* ***	*0.399* **	*0.242* *	*0.179* **	*0.244* ***	*0.190* ***	*0.905* *
CV %	*32.1*	*7.4*	*11.6*	*8.1*	*8.2*	*10.4*	*40.5*

$^{a, b, c}$ means with the same script are not significant at $P = 0.05$, * $P < 0.05$,** $P < 0.01$, *** $P < 0.001$

The additional water at HPW allowed all cultivars not only to produce much greater yields, but also to have much higher oil contents, *i.e.* the mean oil content at HFR was 29.1 % compared to 35.7 % at the HPW site (Table 3). There was a considerable difference between cultivars, especially at HPW where the dedicated oil cultivars (*e.g.* Saffola 555, Saffola 517 and S6005) had far greater oil contents than the birdseed types (*e.g.* Saffire). With high amounts of available water, the linoleic cultivar Saffola 555 produced 1635 kg oil/ha, which was significantly greater than all other cultivars (Sironaria = 1146 kg/ha), except the oleic oil cultivars S6005, and Saffola 517 (1527 and 1427 kg oil/ha, respectively). In contrast at HRF, all dedicated oilseed cultivars produced much less oil (< 101 kg/ha) than the dual purpose and birdseed types. 120045 with 206 kg/ha, achieved the highest oil yield.

Table 3: Oil content and proportion of oleic and linoleic acids for HPW and HRF sites

	HRF			**HPW**		
Cultivar	***Oil %***	**Oleic**	**Linoleic**	***Oil %***	**Oleic**	**Linoleic**
UC_1	-	-	-	33.7 ^{b}	73.1 ^{c}	19.8 ^{b}
Saffire	25.1 ^{a}	10.2 ^{a}	82.4 ^{b}	31.4 ^{a}	9.5 ^{a}	83.2 ^{g}
S501	27.9 ^{ab}	10.2 ^{a}	81.4 ^{b}	36.7 ^{c}	9.4 ^{a}	82.2 ^{fg}

AC Stirling	28.1 ^{b}	11.3 ^{a}	81.9 ^{b}	33.8 ^{b}	9.6 ^{a}	82.8 ^{fg}
120043	28.9 ^{bc}	13.1 ^{a}	79.1 ^{b}	36.7 ^{c}	10.6 ^{ab}	81.6 ^{ef}
120045	29.0 ^{bc}	11.4 ^{a}	81.3 ^{b}	33.3 ^{b}	10.1 ^{a}	82.3 ^{fg}
Gila	29.5 ^{bc}	11.9 ^{a}	80.3 ^{b}	34.2 ^{b}	11.6 ^{b}	80.9 ^{de}
Saffola 517	29.5 ^{bc}	62.3 ^{b}	29.7 ^{a}	36.7 ^{c}	73.6 ^{c}	18.6 ^{b}
Sironaria	*29.6* ^{bc}	*12.4* ^{a}	*79.4* ^{b}	*33.5* ^{b}	*12.4* ^{b}	*79.4* ^{c}
Lesaf 175	30.3 ^{bc}	11.9 ^{a}	80.7 ^{b}	37.1 ^{d}	10.6 ^{ab}	82.1 ^{efg}
S6005	31.2 ^{c}	66.2 ^{b}	26.0 ^{a}	38.5 ^{e}	76.3 ^{d}	15.8 ^{a}
Saffola 555	31.4 ^{c}	12.6 ^{a}	79.4 ^{b}	39.4 ^{e}	12.3 ^{b}	79.8 ^{cd}
LSD (5 %)	*2.92* *	*6.50* ***	*6.56* ***	*1.11* ***	*1.14* ***	*1.20* ***
CV %	*4.5*	*13.7*	*4.1*	*1.4*	*2.0*	*0.1*

[a, b , c] means with the same script are not significant at $P = 0.05$, * $P < 0.05$, *** $P < 0.001$

For the oleic cultivars, the oleic component (Table 3) was less at HRF (62 to 66 %), compared to HPW (73 to 76 %). S6005 had a significantly greater oleic component than the other oleic cultivars. Unlike the oleic cultivars, the linoleic cultivars did not display a large variation in the linoleic component of oil between sites. There was no significant difference in the mass of 1000 seeds at HRF (mean = 30.0 g), but there were a number of significant differences between cultivars at HPW, ranging from 36.1 (S6005) to 42.6 g/1000 seeds (UC_1).

Later in the season (November/December), rust (*Puccinia carthami*) and Alternaria (*Alternaria carthami*) infected both Horsham trials, but did not appear to substantially reduce yields. There was no significant difference in the extent of Alternaria between cultivars, with an average of less than 6 % of the leaves being covered in lesions. Rust appeared most severe on older leaves and there were significant differences between cultivars at both sites. Lesaf 175 appeared most resistant with Gila, UC1, 120043 and UC_1 being worst effected.

As expressed by the seed yields, the mean total water use (stored soil water to 2 m depth + rainfall) for all cultivars between sowing and maturity at HRF and HPW was 285 and 498 mm, respectively. There was no significant difference in total water use between cultivars from sowing to flowering, or sowing to maturity at either site. On average, less than 100 mm of the total amount of water used was extracted from the soil at HRF and this was deemed to be all that was available. The remaining 186 mm fell as rain, often in small amounts that were susceptible to direct soil evaporation. At HPW, the mean amount of water extracted from soil was 297 mm and 201 mm fell as rainfall between sowing and maturity. Overall, only 35 % of total amount of water used at HRF was derived from soil, compared to nearly 60 % at HPW. Because deep soil water is less prone to direct soil evaporation than small rainfall events, HPW not only had more total water, but also is likely to have transpired a larger proportion compared to HRF, thereby explaining the large difference in seed yield and quality between the two sites.

The mean water use efficiency (WUE) for seed yield across all cultivars was also much higher at HPW (7.6 kg/ha/mm) than HRF (1.3 kg/ha/mm). Although total water use was similar for all cultivars within each site, significant differences in seed yield led to significant differences in WUE between cultivars. WUE followed a similar pattern to seed yield, ranging from 0.6 (S6005) to 2.4 kg/ha/mm (120045) at HRF, with Sironaria achieving 1.6 kg/ha/mm. At HPW, UC_1 had the lowest WUE (6.7 kg/ha/mm) and Saffola555 had the highest WUE (8.4 kg/ha/mm), with Sironaria being 7.1 kg/ha/mm.

Conclusion

These experimental sites incorporated a range of environments in southeastern Australia. Water use measurements at the core sites showed no significant difference between cultivars within each core site. However, the substantial range in mean site yields could be attributed to the differences in total water availability between the sites. In terms of seed yield, Sironaria performed well at most sites but was not the highest yielding cultivar at all sites. Further more some of the other cultivars produced significantly higher seed yields and higher oil contents, making them more attractive to growers and marketers. Some of the cultivars have a high oleic content that is desired by the edible oil industry. The more promising cultivars for birdseed production are AC Stirling and Saffire, both having similar yields to Sironaria. The high linoleic cultivar, Saffola 555, yielded exceptionally well at two sites and had one of the highest oil contents of the cultivars included in the experiments. With high seed yields (expect HRF) and a good oleic oil content, S6005 is a promising cultivar that could have a high marketing potential, warranting further evaluation in south-eastern Australia.

No one cultivar preformed significantly better than all cultivars at all sites. The number of safflower cultivars screened in these trials were limited by availability in Australia. Internationally, there are numerous cultivars, including some hybrids, which could be better adapted to southeastern Australia.

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