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New high quality oil seed crops for temperate and tropical Australia

A report for the Rural Industries Research and Development Corporation

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Foreword

The oilseed industry is the most rapidly expanding of all the major agricultural enterprises in Australia. It is currently dominated by Canola (*Brassica napus*), which is grown on over 250,000 hectares in southern Australia. The main aims of the project were to introduce new edible, therapeutic and industrial oil seed options to Australia. The emphasis was on environments in which canola is not well adapted such as very dry areas, or those with incipient waterlogging, sandy soils or saline conditions.

Edible oil seeds endemic to Ethiopia and Botswana initially formed the major basis to fulfill the aims of the study. Two of the species are in cultivation; Niger (*Guizotia abyssinica*), or Noog as it is known in Ethiopia is cultivated in Ethiopia, India and Nepal and Crambe (*Crambe abyssinica*) in North Dakota USA. Noog was observed to be a robust crop growing on poorly drained soils in the highlands of Ethiopia where it is highly prized for its oil quality. There, it is grown in rotation with legumes such as faba beans (*Vicia faba*) and grass pea (*Lathyrus sativus*).

Crambe, also endemic to Ethiopia, has been developed as an industrial oilseed in America. The seed oil contains a very high proportion of erucic acid (60 – 65%), highly valued as a surface lubricant and plasticiser. Its further advantages were stated to be its early vigour and competitiveness with weeds. In the USA it has proven more tolerant of heat stress than canola and higher yielding in short seasons. Crambe is reported to have tolerance to salinity.

Morama (*Tylosema esculentum*), a hardy perennial legume endemic to the Kalahari Desert in Botswana, was included for its ability to grow in very low rainfall areas and vegetate marginal areas productively.

The project was extended in its first year to include potential 'health oils' False Flax or Camelina (*Camelina sativa*), an ancient industrial oilseed with potential as a healthy food oil due to its content of alpha linolenic acid, an Omega 3 fatty acid. Also, Stock (*Matthiola incana*), Borage (*Borago officinalis*) and naturalised species of Evening Primrose (*Oenothera spp*.), all of which have potential as health food supplements.

The report covers the agronomic and quality assessment of the test species and the germplasm acquisition. Field trial data is also provided wherein commercial lines of canola were used as controls. In the last 18 months of the project, a line of Indian mustard (*Brassica juncea*) and lines of Ethiopian mustard (*Brassica carinata*) were added as alternative controls.

This project was funded from RIRDC Core Funds, which are provided by the Federal Government.

This report, a new addition to RIRDC's diverse range of over 900 research publications, forms part of our New Plant Products 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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Dr Oxana Dzyuba, Vavilov Institute St Petersburg provided many oilseed accessions through her Institute as well a taxonomic advice and during her stay in Australia (supported by the Crawford fund) made a valuable contribution to the field and oil quality data.

USDA oil seed germplasm collection Iowa for supply of Crambe accessions

Dr Jon Clements with Mr. B Mishra of the Nepal Agricultural Research Council undertook an extensive collection to provide accessions of Niger (*Giuzotia abyssinica*) for the project.

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Executive Summary

RIRDC project UWA47 commencing in July 1998 to terminate Dec 2002, had as its initial focus; a) the leguminous oilseed Morama bean (*Tylosema esculentum*), native of Botswana, b) Niger or Noog (*Guizotia abyssinica*) the subtropical favored food oilseed of Ethiopia, and c) Crambe (*Crambe abyssinica*) also a native of Ethiopia, commercially produced in USA for use as an industrial lubricant. In the second year of the project the potential value of oilseeds rich in essential fatty acids: Stock (*Matthiola incana*), Borage (*Borago officinalis*) and *Camelina sativa* (Gold of pleasure), were included. As part of the essential fatty acid research a survey of the gamma linolenic acid content of locally adapted evening primrose (*Oenothera spp*.) relatives was initiated after discussion with the RIRDC Research Manager. 'Control' species were expanded from canola to include condiment oil seeds: Indian mustard *(Brassica juncea*), Ethiopian mustard *Brassica carinata* and later linseed (*Linum usitatissimum).*

Plans to finish the project with tonne quantities of Camelina, Crambe and Niger, thus setting the path to the rapid development possible with oil seeds given their relatively low seeding rate requirements, received a setback with the severe drought in NSW and parts of SA scheduled for initial seed production. However Kg quantities are still on hand and new sowings planned for 2003 are to be coordinated by commercial partner Elders Ltd.

Being new species, germplasm acquisition and preliminary assessment have been an important part of the initial years of the project with 113 lines of Niger, 99 lines of Camelina, 32 Crambe, 39 stocks, 27 Boraginaceae and 15 lines of Evening primrose or its relatives now included in our collection. Most lines of Niger arose from a plant collection tour in Nepal in 1998 and the Camelina lines were largely supplied by the Vavilov Institute St Petersburg from their extensive oil seed collection. Niger lines have been lodged with the Australian Tropical Crops Genetic Resource Centre, Biloela, with others being forwarded to the ATFC collection at Horsham.

Camelina yielded approximately 1.7 tonnes per hectare and in general, yielded less than the Canola controls. This situation was reversed at Miling in 2000 and on sandy soils at Merredin in 2001 where it significantly outyielded Karoo canola. It is regarded as a low maintenance crop in Europe and appears adapted to low fertility situations. The relatively small seeds (approx.1000 per gram) contain up to 40% oil. The oil contains around 34 % Omega 3 fatty acids (Canola ca 9%) making it a very rich plant source of this essential fatty acid. Selection for oil content and level of Omega 3 was undertaken together with selection for lodging resistance. The pale straw colour of the oil makes any bleaching unnecessary and its apparent keeping quality enables cold pressed oil with a high Omega 3 content. This makes it a potentially attractive product. Unlike several countries in Europe where it is used in salad oils and margarines, it is not yet registered as food oil in Australia. Besides export, its immediate use may to be in skin health preparations where its pale colour and good emollient qualities make it a good basis for creams and lotions.

Crambe has been shown to be agronomically suited to South Western Australia and sufficient seed will be available by the end of the project for initial farm scale seed increase. The extent of the increase will however depend on a market for the specialty oil. Its early vigour made it more competitive with weeds than the other oil seed species in field trials. Yield and oil were comparable to those recorded in its main growing center in North Dakota USA. The best yield of hulled seed recorded was 3.1 t/ha with an oil content of the hulled seed of 30 %, which equates to a 50% content of dehulled seed. The oil consistently had an erucic acid content above 60 percent. These figures equate with USA data for the species. So far there are no quality or agronomic problems associated with its production at least in southern Australia. Further seed increase can be rapidly undertaken with commercial quantities available in 2 years but the future development depends on a market being established.

Niger is a tropical subtropical species. It is strongly crossed fertilised and requires bees for good seed production. It grows rapidly in spring and early summer in Perth but it is not well adapted to Mediterranean climates other than those relatively restricted warm climate areas, which would be essentially frost-free. Its place will be Northern NSW and Queensland or areas where summer irrigation is available. Lines of Ethiopian origin were taller and later in maturity but more tolerant of cool winters than the Nepal lines assessed during the project. The oil, typically around 38% of the seed, is an attractive pale yellow in colour. With a linoleic acid content of 79% it is very similar to sunflower oil and an attractive product. Whilst it has good oil quality, there is an immediate demand in the high priced birdseed market for export to USA. The very limited germplasm base of Niger in Australia has been substantially increased through a collection mission in Nepal and some direct introductions from market samples in Ethiopia. 20 kg of seed was made available for farmer assessment and seed increase in NSW under the supervision of commercial partner Elders Ltd. Drought conditions have forced a delay in this program till late 2002 –2003.

Morama, a native of Botswana where it is prized by people of the Kalahari desert for the protein and oil content of it very large seeds (20-30 gm), is successfully growing in Perth. Vegetative growth is very vigorous during the summer months arising from a massive underground tuber. Winter dormant, it is clearly tropical and under our summer conditions has yet to set seed. A promise of additional seed from Botswana following Ms Campbell's visit in 1999 has not been forthcoming but it is yet possible seed will be produced from the plants growing locally.

Evening Primrose (*Oenothera biennis*) oil is widely marketed as a source of the essential fatty acid, gamma linolenic acid (GLA). *Oenothera spp* are naturalised and widespread in the Perth metropolitan area and 4 species were included in a survey from samples taken from Perth roadsides. They are well adapted to sandy soils, though to date under our hot summer conditions, the gamma linolenic acid content has, with the exception of one species generally been far less that the 9 percent claimed as a minimum standard for commercial evening primrose oils. Under Perth conditions *O. biennis* produced only 8 % GLA. One of the members of the evening primrose family naturalised in Western Australia and other states, *Oenothera glazioviana* (tall evening primrose) produced levels in bulk samples of up to 9 % GLA suggesting a program of single plant selection should yield GLA levels of the required standard. The tall species is biennial and flowers in midsummer. The fruits of all the *Oenothera* species shatter on maturity creating difficulties with seed harvest. In this respect 'tall evening primrose' appears to have some advantage with the upright pods less prone to shedding seed on maturity. The species deserves further investigation as an alternative producer of Evening Primrose Oil.

Several members of the Boraginaceae (including Paterson's Curse) have proven equal to or higher in gamma linolenic acid (GLA) than the traditional source marketed as evening primrose oil (ca 9 % GLA). Borage itself is in demand with some 40 tonnes of seed being sought in 2002. Borage grows vigorously and the seed contains 34 - 37 percent oil with 19 - 25% GLA in the oil. Its performance in yield trials was generally poor. Despite yielding 455 kg/ha at one site in 2001, yields on average were less than 200 kg/ha. Its propensity to shatter makes it a difficult plant to manage on a large scale at least with the lines at our disposal. Cooler conditions e.g. southern Victoria or Tasmania may reduce the shattering and combined with swathing could yield profitably. There is a good UK market and Borage oil is a well-established product marketed as Starflower oil. Less shattering lines as claimed in the UK would be an advantage.

The common garden stock (*Matthiola incana*) was unique in its high content (65 %) of Omega 3 fatty acids. A perennial, several naturalised lines have demonstrated ability to produce as an annual crop. Best of these is a line arising from a farmer's property. This line 'Frank Stone' is capable of setting seed in its first year of cultivation. The earliest maturing line LO 23, selected in Israel, performs as an annual under Perth conditions. A new line from Samos, besides its good seed set, has real potential as an ornamental plant with its attractive dual flower colour. The main disadvantages of the stocks however is their comparatively low content of oil in the seed (ca 22%) together with very slow early growth exposing them to weed competition. The harvesting technology also needs further development.

Marketing information was developed during the course of the project. Oil samples were prepared using a Komet oil expeller and visual and taste assessment carried out on the extruded oils. The clarity and pale straw colour of Camelina relative to Canola was noted and it appears well suited to the production of cold pressed unbleached health oils. The Niger oil was also of pale yellow colour and likewise would not require further bleaching. Taste panels reported favourably on the flavour both of Camelina and Noog oil. Oil samples were prepared for potential customers of the products.

RIRDC supported a visit by Ms Campbell to international marketing outlets for the alternative oil seed products, which included 3 UK companies Limagrain in France and Camelina Ltd in Finland. This was highly a successful adjunct to the research program in providing marking information and potential market outlets for the oils or seed resulting ultimately from the project. Seed and oil samples are to be forwarded to UK companies. During the course of this investigation and in queries to the USA, the potential of Golden flax and Echium in the health market became apparent and germplasm was accumulated in the final growing season of project UWA47A.

For the benefit of potential growers, agronomic recommendations for Camelina, Crambe and Niger, together with alternative chemicals for weed and insect control have been included in Appendix 2.

1. Introduction

The oilseed industry in southern Australia totals more than 250.000 hectares and the opportunity exists to at least double the area. Market prospects for highly polyunsaturated oils are continuing to expand rapidly. In Australia the oilseed industry is based almost solely on Canola. Whilst canola has been an overall success story it is poorly adapted to some important environments. For example poorly aerated soils with incipient waterlogging, sandy soils, mildly saline soils and dry margins of the wheat belt generally. In some of these it was considered new oilseeds could well have a place and the project was set up to explore avenues for their use and production. In the initial stages of the project it became clear that an additional set of alternative oil seeds for which there was growing demand in health and therapeutics could also be suited to Australian conditions.

The project had as its initial focus a) the leguminous oilseed Morama (*Tylosema esculentum*) bean native of Botswana, b) Niger (*Guizotia abyssinica*) the Subtropical favourite oilseed of Ethiopia and c) Crambe (*Crambe abyssinica*) produced commercially in USA for it industrial use as a consequence of it high erucic acid content. With the increasing demand for oils with therapeutic or health benefits, the potential value of oilseeds rich in essential fatty acids; gamma and alpha linolenic (Omega 3) acids were introduced to the project. These include species high in Omega 3, Stock (*Matthiola incana*) and Camelina or Gold of Pleasure (*Camelina sativa*). Species with high gamma linolenic (GLA), Boraginaceae (*Borago officinalis and Echium*) were introduced. As part of the essential fatty acid research, a survey of the GLA content of locally adapted evening primrose (*Oenothera sp.*) relatives was initiated given the widespread sales of Evening Primrose oil. Yield and adaptation were seen as key characters and 'control' species were expanded from Canola to include condiment oil seeds: Indian mustards *(Brassica juncea*) and Ethiopian mustard (*Brassica carinata*) and later linseed.

2. Objectives

The major outcome sought during the research was to introduce new edible, health and industrial oil seed options to Australia within the time frame (4.5 years) of the project. Emphasis was on environments to which current Canola cultivars are less well adapted such as very dry areas, those with incipient waterlogging, sandy or saline conditions. Edible oil seeds endemic to Ethiopia and Botswana formed the main basis of the initial study. Two of the species were in cultivation, Crambe in the USA for quality industrial oil and Niger as the preferred edible oil in Ethiopia, Nepal and India.

3. Methodology

A major emphasis has always been on germplasm acquisition as the number of accessions in Australian collections of the key species was very limited. Linkages already developed in Ethiopia and Nepal together with excellent linkages to the Vavilov Institute collection and USDA in other projects were used to expand the germplasm base.

Seed of all new germplasm was assessed for oil content and quality at the end of the first growing season. The quality focus was on high levels of erucic acid in Crambe (*Crambe abyssinica*) as industrial oil and high polyunsaturated fatty acids in the edible oil of Niger (*Giuzotia abyssinica*), Camelina (*Camelina sativa*) and the unique perennial species Morama. (*Tylosema esculentum*). Oil quality was assessed by standard GLC methods and oil content by Soxhlet and NMR technology. The oil analysis of the transesterified triglycerides was carried out on a GC-17A V3 (SHIMADZU, Japan) using helium as the carrier gas and hydrogen as the detector gas (Jimenez de Blas, 1996).

Seeding of the alternative oilseeds was carried out under replicated standard length double row conditions at Shenton Park Research Station. This allowed seed bulk up and provision of preliminary agronomic information on maturity, plant form and height, lodging resistance, shattering and yield potential. Yields of the most promising lines selected at Shenton Park Research Station were assessed at up to 3 regional sites per year in Western Australia with the assistance of the commercial partner. Yields were measured against controls of Canola, mustards and linseed. Plot sizes of 1.6 x 10 m allowed machine sowing and harvest of the test lines.

The efficacy of a wide range of herbicides and any adverse effects on the test species were measured and formed part of the agronomic package to accompany recommendations on release.

4. Detailed results

4.1 Comparative yields

The comparative yields of different species harvested from the country trials in 2000 and 2001 expressed in tonnes pre hectare, are presented in table 1. Yields of the test species Camelina and Crambe are shown, as are the yields of the controls, Canola, the mustards, linseed and linola. Not included in the table are Borage and Noog. Although grown in most of the trials, Borage consistently failed to reach its potential. Vegetative growth was good but seed harvested was very poor in 2000 and 2001. In 1999, Borage yielded comparatively well with the equivalent of 0.455 tonnes/hectare of seed recovered at Meckering and 0.396 tonnes/hectare at Northampton. That year, the control, Canola cv. Maluka, yielded the equivalent of 0.197 tonnes/hectare at Meckering and 1.428 tonnes/hectare at Northampton. However, in subsequent years the yield of Borage was less than 0.01 tonnes/hectare.

Noog showed promise in the initial trials, yielding up to the equivalent of 0.73 tonnes/hectare at the Northampton site in 1999. However, it yielded less well at Meckering that year, with a maximum seed production of the best line equal to only 0.109 tonnes/hectare and in trials in the following years, it yielded very poorly producing less than the equivalent of 0.05 tonnes/hectare.

Table 1. Comparative yields of the oilseed species grown in the country trials in 2000 and 2001

		2000	**2000**	**2000**	**2001**	**2001**	**2001**	**2001**	**2002**
Species	**Line**	**Miling**	**Northn**	**Wagin**	**Miling**	**Wagin**	**Mrrdin**	**Northam**	**Mgnew**
Canola	Karoo	2.1	0.1	0.7	2.6	0.0	1.6	0.1	
Canola	Outback								0.8
B. carinata	193467	3.0	0.3	**1.5**	2.1	1.2	1.2	0.2	0.7
B. juncea	Original	**3.5**	0.2	**1.9**	2.1	2.5	1.4	0.2	0.6
Camelina	4164	**2.9**	0.6	1.1	1.2	1.2	**1.8**	0.2	0.6
Camelina	CSA				0.8				
Camelina	R339	2.1	0.2	1.2			**2.1**	0.1	0.6
Camelina	4138	**2.3**	0.7	1.1					
Camelina	4183				1.3	1.5			
Camelina	4184				1.0	1.2			
Crambe	94053	2.8*	1.6*	1.3*	2.1*	1.4*	1.7*	0.2*	0.5*
Crambe	Bel Ann								
Crambe	Meyer								
Crambe	K 10				2.2*	1.8*			
Crambe	K 32	3.1*	1.4*	1.3*					
Crambe	337110	3.0*	1.5*	1.3*			2.0*	0.4*	0.8*
Crambe	32855				1.8*	1.4*			
Linseed	Glenelg	2.0	0.8	0.8	1.8	1.0	0.4	0.2	
Linola	Walaga	1.7	0.2	0.8	1.6	0.4		0.2	0.2

* The seed of Crambe is harvested complete with its fruit coat, i.e. the seed is hulled.
Please see Appendix 2 for site details.

4.2 Comparative oil content and quality

The species evaluated during the project have different market niches depending on the fatty acid composition of their oil. A comparison of the typical oil composition for each species against those of the controls; Canola cv Karoo and Linseed cv Glenelg is given in Table 2. The values for the fatty acids are expressed as percentages of the total fatty acid composition. The fatty acid most important for the marketing of each species is highlighted. More detail for each species is given in subsequent tables.

Table 2. Percentage oil content and quality typical for each species

Fatty Acids	Canola	Borage	Evening P.	Camelina	Crambe	Guizotia	Matthiola	Linseed
Saturated	7	17	10	8	5	13	11	9
Oleic	**60**	19	10.5	16.5	14.5	6	14	18
Linoleic	21	36	65	16.5	8	**80**	13	18.5
g-Linolenic		**22**	**9**	0.1				
a-Linolenic	**10**			**36**	7	0.5	**60**	**54**
Eiconsenoic				**16**				0
Erucic	1	3		3	**62**	0.5		0.5
Oil content	40	35	22	38	32	38	22	38

A contribution toward equipment for small-scale oil extraction was approved by RIRDC in 2001/02-budget year. This provided oil samples for panel tasting, colour analysis and prospectively for measurement of keeping quality. Some initial data on appearance is shown below. Camelina in particular has attractive pale oil and appears well suited to production of cold pressed, unbleached health oil.

Table 3. Cold pressed oil extractions – first press from 1 Kg of seed

Species	Oil extracted (ml)	Percent extracted (First press)	Oil colour
Canola	350	83.3	7A* yellow
Niger	310	86.0	6D pale yellow
Camelina	300	81.1	5D pale straw
Linseed	275	88.0	8A yellow
Crambe (in hull)	225	72.5	7B yellow

* Kew Gardens Horticultural flower colour standards

4.3 Oil content and quality for each species

The oil content and fatty acid profile of each species or group of related species showed some variation between the lines tested. The source of the variation can be attributed to both genetics and environment.

4.3.1 Camelina

To gain an indication of the genetic variation in the species, thirty-two lines, grown in a common garden situation during the winter of 2001, were assessed for a number of characteristics. A summary of the results is presented in Table 5. (For more detail see Appendix 3). The greatest difference noted was in the seed size; the smallest seeded line being almost a third of the size of the largest seeded line. However, 72% of the lines had a 1000 seed weight of between 0.8 and 1.0 gram. The maximum differences between accessions in levels recorded for the most important of the fatty acids were 5.76% for the Omega 3 (Alpha linolenic acid), 3.23% for the Eicosenoic acid and 1.76% for the Erucic acid. The oil content of the seed varied by a maximum of 7 % between the different lines.

Table 4. A summary of the variation noted in seven characteristics between 32 lines of Camelina grown in at the UWA Research Station in Perth WA, in 2001.

Characteristic	Minimum	Maximum
% Oil content of the seed	32	39
% Oleic acid	12.36	18.65
% Linoleic acid	15.14	22.52
% Omega 3	31.18	36.94
% Eicosenoic acid	13.48	16.71
% Erucic acid	2.45	4.21
1000 seed weight (g)	0.66	1.61

The influence of environment on oil quality was assessed by testing the oil of 3 lines grown in different locations in WA during 2000. (See Appendix 2 for site details). The resulting values are given in Table 5. The results indicate that although both genetics and environment had an effect on the oil quality, the greater influence was between the lines. That is, in this instance, inheritance was more important than the environment. However, the differences were generally small and would have little effect ultimately on the properties of the oil.

Table 5. A comparison of the fatty acid profiles of Camelina grown in 4 different sites.

Line No	Site	% Oleic	% Linoleic	% Linolenic	% Eicosenoic	% Erucic
4164	Field Stn	14.2	20.3	33.1	15.4	3.6
	Miling	19.1	17.0	33.1	15.5	3.9
	Northampton	17.9	16.5	32.9	15.5	3.0
	Wagin	18.4	17.5	31.9	16.3	3.7
R339	Field Stn.	18.7	15.1	33.2	16.5	3.3
	Miling	19.7	16.0	34.1	15.7	2.4
	Northampton	18.6	14.9	34.6	16.2	3.2
	Wagin	18.8	16.6	33.7	15.9	3.0
4138	Field Stn.	13.8	17.9	37.1	14.9	3.0
	Miling	17.5	19.6	34.3	13.9	2.3
	Northampton	16.1	18.7	34.3	14.7	3.2
	Wagin	16.4	18.8	34.3	15.1	3.0

4.3.2 Crambe

The seed oil of Crambe is a very rich source of erucic acid, which is in demand for industrial lubricants. Erucic acid is a long-chain mono-unsaturated fatty acid. Both genetics and environment have an influence on the composition of the oil. Table 6 contains a summary of the data obtained from the analysis of 21 lines of Crambe grown at the UWA Research Station in Perth in 2001. Except for one line, which recorded a relatively low level of 54.6% in its erucic acid content, the variation between the lines was less than 3%. The oil content of the hulled seed varied the most, with the maximum difference being 7.4%. This was probably related to the variation in thickness of the fruit coat. (See Appendix 4 for more detail).

Table 6. The minimum and maximum values for percentage oil content and the fatty acids found in the seed oil of 21 lines of Crambe grown at Shenton Park, WA.

Characteristic	Minimum	Maximum
Oil content of the fruit	28.9	36.3
Oleic acid	13.4	19.1
Linoleic acid	7.6	8.8
GLA	5.0	6.3
Omega 3	2.0	5.5
Erucic acid	54.6	63.4

To assess the influence of environment on the oil quality, seed from three lines of Crambe grown at four different sites in WA in 2001 was analyzed. (Table 7). See Appendix 2 for site details. Generally, there was little variation in the fatty acid profiles, with the greatest difference in the level of erucic acid (5.2%) being due to the influence of environment. The highest level of erucic acid was obtained from seed grown at Wagin (68.5%), the most southerly site and the one with the longest and coolest growing season.

Table 7. A comparison of the fatty acid profiles of 3 lines of Crambe grown at 4 different sites during 2001

Line No	Site	% Oleic	% Linoleic	% Linolenic	% Eicosenoic	% Erucic
94053	Field Stn.	13.7	7.5	5.7	1.0	66.5
	Miling	15.1	7.0	5.6	1.8	64.2
	Northampton	14.2	7.7	6.2	1.8	62.9
	Wagin	13.6	7.2	5.5	1.7	66.1
337110	Field Stn	14.0	7.6	5.9	1.2	64.7
	Miling	15.3	7.2	5.6	1.8	63.3
	Northampton	13.6	7.8	6.3	1.7	63.7
	Wagin	13.9	6.5	4.3	1.4	68.5
K32	Field Stn.	13.8	8.4	6.4	1.3	63.1
	Miling	15.5	7.5	5.9	2.0	62.3
	Northampton	14.4	7.1	5.5	1.6	65.3
	Wagin	14.1	7.9	5.4	1.8	65.0

The percentage oil content of three lines of Crambe grown at four sites in 1999 was compared. The results are shown in Table 8. For each of the species the highest oil content recorded was for lines grown in the Screen House at the UWA Research Station in Perth. This is a sheltered environment in which temperatures usually are 2 – 3 degrees C higher than in the open and where irrigation for the plants is available.

Table 8. A comparison of the percentage oil content of the seed of 3 lines of Crambe grown at 4 different sites during 1999

Line	Site	% Oil content
ATC 94053	Field Stn.	27.4
ATC 94053	Screen House	29.0
ATC 94053	Meckering	23.1
ATC 94053	Northampton.	20.4
Bel Ann	Field Stn.	27.0
Bel Ann	Screen House	28.5
Bel Ann	Meckering	27.3
Bel Ann	Northampton	22.6
Meyer	Field Stn.	26.1
Meyer	Screen House	38.0
Meyer	Meckering	28.3
Meyer	Northampton	29.4

4.3.3 Noog or Niger

The oil extracted from the seed of Noog is the preferred food oil of Ethiopia. The major fatty acid of the oil produced in Ethiopia is Linoleic acid and it usually comprises between 75 and 80% of the total fatty acids in the oil. As shown from lines grown in a uniform environment in a screen house at Shenton Park Research Station, there were genetic differences. The seed originating from Nepal is much more variable in fatty acid composition as indicated in the values shown in Table 9. The percentage of Linoleic acid in the oil can vary from 30 to 77. More detail can be found in Appendix 5. The results show that it is the more saturated fatty acids that increase with any decrease in the level of Linoleic acid. The range of differences in the levels of Palmitic acid and Stearic acid were 22.6 and 19.4 percent, which largely accounted for the 47.1 percent difference in the concentration of Linoleic acid found in the Nepal lines. The Oleic acid level was more stable, the difference being 7.5 percent.

Table 9. A summary of the variation found in the fatty acid profiles of 44 lines of Niger

Origin	No. of Lines	%Palmitic	% Stearic	% Oleic	%Linoleic
Ethiopia	4	8.8 – 9.5	6.5 – 6.7	7.1 – 9.5	73.1 – 75.4
Nepal	37	8.1 – 30.7	5.1 – 24.5	3.8 – 11.3	30 – 77.1
Poland	1	8.3	8.4	18.2	63.3
Portugal	1	8.8	7.6	8.6	73.4
Spain	1	8.3	6.7	14.9	68.7

4.3.4 Evening primrose

A collection mission around Perth and south western WA resulted in a germplasm base of several lines of four different naturalised species of *Oenothera.* The oil content and fatty acid profiles of these were assessed and compared to a line of the commercial species *Oenothera biennis* grown in WA. A summary of the results is shown in Table 10. *O. drummondii,'* Beach Evening Primrose', had the best oil content but *O. glazioviana*, 'Tall Evening Primrose', had the better fatty acid profile for potential commercial purposes. It had up to 9% GLA compared to a maximum of 2% found in the other species.

Table 10. The oil content and quality of some *Oenothera* species growing in WA

Fatty acids	O. biennis	O. drummondii	O. glazioviana	O. mollissima	O. stricta
Palmitic	5 – 7	10 – 11	5 – 7	8 - 10	8 – 10
Stearic	1 – 2	2 – 3	1 – 2	2 – 3	3 – 4
Oleic	13 – 16	16 – 17	9 – 10	11 – 13	8 – 10
Linoleic	67 – 73	67 – 77	75 – 77	70 – 75	74 – 78
GLA	6 - 8	0 – 1	6 – 9	1 – 2	1 – 2
Erucic				2 – 4	
% Oil	10	29 – 30	22 – 25	19 - 22	25 - 28

4.3.5 The Boraginaceae

The Boraginaceae family includes a number of different species that have been cultivated for centuries in Europe as herbs with therapeutic properties. One of them, *Echium plantagineum,* is a very well known and widely spread weed of various states of Australia, known locally as Paterson's Curse. This has gained interest because its seed oil contains an uncommon fatty acid with anti-inflammatory properties - stearidonic acid. The oil also contains an appreciable amount of Omega 3 fatty acid and a percentage of GLA equivalent to that found commonly in Evening Primrose. *Anchusa officinalis*, summer forget-me-not, was tested but the oil content of the seed was too low to have a potentially commercial profile. Borage seed has a reasonable oil content (34 – 37%) and the oil contains up to 25% GLA.

Table 11. The oil content and oil profile of four members of the Boraginaceae

Fatty acids	Anchusa	Borage	Paterson's curse	Dwarf Echium
Palmitic	8 – 10	11 – 13	7 – 10	8 – 11
Stearic	1 – 3	3 – 5	1 – 4	5 – 8
Oleic	21 – 28	15 – 19	15 – 21	18 – 22
Linoleic	27 – 30	34 – 37	15 – 21	15 – 20
GLA	9 – 10	19 – 25	8 – 10	8 – 10
Omega 3	14 – 19		28 – 35	20 – 28
Stearidonic			7 – 13	7 – 9
Erucic	2 – 3	2 - 4		
% Oil content	20 – 24	34 - 37	19 – 22	20 – 25

4.3.6 Matthiola

Matthiola incana, commonly known as garden stock and cultivated for its ornamental qualities, has seed oil that contains a high percentage of the Omega 3, Alpha Linolenic acid. It is a perennial species that belongs to the Brassicaceae family. Its perenniality depends largely on environmental conditions. In trials, some plants have survived for four years, others have acted more as annuals or biennials. Table 12 shows the fatty acid composition of the oil of 6 lines of Matthiola. The seed was harvested from plants grown in different years at different sites. In 2001, some plants of the Matthiola line 'Frank Stone', were swathed and left to dry while others were left for the fruit to dry on the plant. Carried out at the UWA Research Station in Perth the results in the table indicate that swathing may well arrest the formation of the desirable long chain Omega 3 fatty acid. Further work is needed on this aspect.

For commercial potential, the level of Omega 3 fatty acid in the oil would need to be greater than 60%. Only two of the lines tested had the required level but there are more lines available for assessment.

Table 12. The fatty acid content of the oil of six lines of Matthiola

Line	Site	Year	Palmitic	Stearic	Oleic	Linoleic	Linolenic
Frank Stone	Dalwallinu	1999	8.0	3.5	2.0	10.5	55.7
Frank Stone	Field Stn	2000	8.7	3.6	14.5	14.1	57.0
Frank Stone	Northampton	2000	8.5	3.4	14.5	15.2	56.6
Frank Stone	Dalwallinu	2000	8.6	3.2	15.5	13.0	57.7
Frank Stone	FS (swathed)	2001	10.5	3.7	15.8	11.9	51.5
Frank Stone	FS (unswathed)	2001	9.6	3.7	14.8	10.8	57.4
Frank Stone	Northampton	2001	9.4	4.3	17.0	14.8	53.2
Trigg	Trigg, Perth	1999	7.2	3.2	11.1	10.4	66.8
JW M6	Perth garden	1999	8.7	2.5	16.0	9.0	52.3
Roz 46	Field Stn	2000	8.7	2.7	14.1	11.8	61.8
NBJ	Northampton	2000	8.2	3.3	15.0	14.2	57.7
NBJ	Northampton	2001	9.2	4.1	15.0	15.7	55.0
NBJ	Field Stn	2001	9.2	3.6	15.0	10.0	61.4
NBJ	Wagin	2001	9.3	4.1	15.1	15.5	55.4
Samos	Field Stn	2001	9.0	4.3	15.4	12.4	58.5

4.3.7 Morama

Morama (*Tylosema esculentum*) is a perennial, leguminous vine, native to the Kalahari Desert in Botswana. Prized for the protein and oil content of its large seed by the San people, the 8 plants growing at the UWA Research Station in Perth have so far failed to produce seed. The seed and leaves were analyzed for oil content and quality and compared to canola. The results are shown in table 13. The oil content of the seed kernel was 41.7% compared to the 43.5% for the canola. The Oleic acid and Linoleic acid content of the oil at 49% and 23.5% was comparable to that of the canola. The protein content of the seed kernel was 38.4%. This was almost double that of the canola seed (21.3%).

Table 13. A comparison of the oil content and quality typical of the seed and leaves of Morama and Canola

Species	Plant part	% Oil	Palmitic	Stearic	Oleic	Linoleic	Linolenic	Erucic
Canola	Vegetative	5.7	8.5	1.5	0.5	8.0	42.0	22.0
Canola	Seed	43.5	4.2	1.8	59.7	21.0	11.0	0.4
Morama	Vegetative	35.7	20.0	2.8		11.0	14.0	
Morama	Kernel	41.7	12.8	7.3	49.0	23.5	2.7	
Morama	Seed coat	2.0	10.0	4.0	23.0	15.0	2.8	10.5

4.3.8 Seed stocks

Table 14. Weight of seed available for bulk up

Species	Line	On hand	With Elders
Camelina	4164	8 kg	10 kg
Camelina	4183	7 kg	5 kg
Camelina	4184	11 kg	
Camelina	CSA	6 kg	
Crambe	94053	18 kg	10 kg
Crambe	K10	12 kg	
Crambe	32855	12 kg	
Niger	Spikes	15 kg	

5. Discussion of results

The 4.5 year project in its first year focused on a) the leguminous oilseed Morama (*Tylosema esculentum*) bean native of Botswana, b) Niger or Noog (*Guizotia abyssinica*) the subtropical favored food oilseed of Ethiopia, and c) Crambe (*Crambe abyssinica*) produced commercially in USA as an industrial lubricant as a consequence of its high erucic acid content. In the second year of the project assessment of the potential value of oilseeds rich in essential fatty acids, Gamma linolenic acid (GLA) and alpha linolenic acid (Omega 3) was introduced as an expansion of the project. This greatly increased the range of species under evaluation. Omega 3 rich species included Stock (*Matthiola incana*), and Camelina or Gold of pleasure (*Camelina sativa*). Camelina with 34 percent or more Omega 3 and cultivatable as a conventional oil seed was particularly promising in outyielding Canola on some soil types. Members of the genus Boraginaceae are typically rich in GLA and the field evaluation included the herb Borage (*Borago officinalis*). As part of the essential fatty acid research a survey of the gamma linolenic content of locally adapted evening primrose (*Oenothera sp.*) relatives was initiated.

Being species not widely utilised in Australia, germplasm acquisition and preliminary assessment have been an important part of the initial years of the project and considerable use was made of CLIMA's international linkages with the Vavilov Institute St Petersburg, National Agricultural Research Council (NARC) Nepal and the USDA national oilseed collection.

The performance of the various oil seed groups, the germplasm acquisition program and seed stocks on hand is outlined in the discussion of the individual species group evaluated during the program.

Given the commercial application of the project it was planned to finish the project with up to 1000 kilograms of Camelina, Crambe and Niger seed. This would set the path to the rapid seed increase possible with oil seeds given their relatively low seeding rate requirements. This plan received a setback with the severe drought in NSW and parts of SA scheduled for initial seed production. However kilogram quantities are still on hand and new sowings planned for 2003 are to be coordinated by commercial partner Elders Ltd.

5.1 Camelina

Camelina sativa (False flax Gold of pleasure) a member of the Brassicaceae is undergoing a resurgence of interest in Europe. Whilst originally cultivated mainly for its fibre, its more modern use is in the food oil industry. Its high content of Omega 3 fatty acid (L linolenic) makes it and invaluable health product.

False flax is resistant to blackleg and is now a small-scale commercial crop in Europe after being widely cultivated pre-war in Russia and Eastern Europe. It is now registered as food oil in Canada and many European countries. It is still the main oilseed cultivated in Siberia. With 80 genotypes and many more available in the Vavilov Institute collection, there are excellent prospects of further improvements in oil and Omega 3 content. Despite having a higher level of polyunsaturated acids than Canola the keeping quality of cold pressed Camelina oil is reported to be sound due to their inherently high content of antioxidants - another quality advantage. The low content of glucosinolates makes the utilization of meals much easier. (Lange et al 1995). It content of 45% protein and 10-11% fibre is comparable to Soya bean meal and a potentially useful product (Korsrud et al 1978).

Camelina yielded approximately 1.7 tonnes per hectare at the best sites but in general, yielded less than the Canola controls. This situation was reversed at Miling in 2000 and on sandy soils at Merredin in 2001 where it significantly out yielded Karoo Canola. It is easy to harvest and shattering is not a problem. There is considerable variation in the degree of lodging so that selection of best standing lines was readily achievable. The yield figures do indicate that in favorable environments the species has considerable potential. Where blackleg is a problem it could prove a highly profitable cleaning crop given the attractive qualities of the oil in terms of its food oil and potential health benefits. In the context of rotation it is better suited to no till and other shallow seeding techniques and suffers far less weed competition. This may in part be due to allelopathic properties (Lovett and Duffield 1981). It is regarded as a low maintenance crop in Europe and appears adapted to low fertility situations. The compatibility of Camelina with no till systems, the low seeding rate of 5 kg or less and the competitiveness with weeds, could enable it to be the lowest input cost oil seed. This is compatible with national goals of reducing energy and pesticide use and protecting soils from erosion.

Amongst the 3 lines of Camelina under evaluation yield differences were not significant. The level of Omega 3 linolenic acid was importantly unaffected by the environments chosen in these studies which did not however include a long season southerly site where oil contents and perhaps Omega 3 level may be highest in keeping with European experience. The relatively small seeds (approx.1000 per gram) contained up to 40% but generally around 35% oil in the sites chosen for yield evaluation. The oils contained around 34 % Omega 3 fatty acids (Canola ca 9%) making it a very rich plant source of this essential fatty acid. Selection for oil content and level of Omega 3 was undertaken together with selection for lodging resistance. The pale straw colour of the oil makes any bleaching unnecessary and its apparent keeping quality enables cold pressed oil with a high Omega 3 content. This makes it a potentially attractive product. Unlike several countries in Europe where it is used in salad oils and margarines it is not yet registered as food oil in Australia. Finland's Camelina Limited was visited by Ms Campbell who noted the range of Camelina products available: Cold pressed extra virgin Camelina oil, Camelina relish, Camelina dressing, Camelina seed and Camelina seed cake all of which have found a small but significant niche in the oil products market of that country. Until registered for food oil in Australia it has, besides export value, an immediate use in skin health preparations where its pale colour and good emollient qualities make it a good basis for creams and lotions.

5.2 Crambe

Although Crambe originated in the mild climates (12 -25 degrees C) of the highlands of Ethiopia it has become adapted to colder and drier regions and compared to Canola and is more resistant to heat and drought at the end of the growing season. In North Dakota USA Crambe is slightly higher yielding than Canola. (Knights 2002). This series of trial has shown Crambe to be agronomically suited to South Western Australia, and undoubtedly other Mediterranean climate regions of southern Australia. Sufficient seed will be available by the end of the project for initial farm scale seed increase. The rate and extent of the increase will however depend on a market for the specialty oil. Its early vigour and leaf cover make it more competitive with weeds than the other oil seed species we have evaluated in field trials. Yield and oil were comparable to those recorded in its main growing center in North Dakota USA. The best yield of hulled seed recorded was 3.1 t/ha. The oil content of the hulled seed was 30 %, which equates to approximately 50% content of dehulled seed. The oil consistently had an erucic acid content above 60 percent. These figures are as good or better than USA data for the species under their conditions. So far there appears to be no serious quality, disease (it is not very susceptible to blackleg) or agronomic problems associated with its production.

RIRDC have recognised the potential of Crambe as a biorenewable resource and commissioned a comprehensive review of current and future potential of the crop (Knights 2002). Crambe produces high erucic acid oil (HEA). These long carbon (C=22) chains have a high fire and smoke point (240 degrees C) and give HEA oil the abilities to withstand high temperatures and remain liquid at low temperatures. These features make HEA oils good lubrication and transfer oils. When converted to erucamide it is used as a slip agent in the plastics manufacturing industry where erucamide keeps the individual sheets from sticking together. It is also used in the textile and steel industries in the USA for spinning lubricants and sheet steel fabrication (Grombacher et al 1993). The biodegradable nature of Crambe oil is an advantage over mineral oils. As a lubricant it has a higher heat removable coefficient that mineral oil at temperatures of 700 C whereas the better mineral oils reach a maximum of 550-600 C a potentially valuable characteristic for the refrigeration industry. It is a stable oil containing 3% of a polyphenol oxidant and was stable for 240 hrs at 180 C in evaluation with 'Rancimat' equipment. This together with the fact that it did not develop sandy oxidation or polymerisation products make it suitable for chain saw lubricants especially as it is biodegradable (Lazzeri 1994).

Low crude oil prices were a major impediment to the introduction of Crambe but greatly increased crude oil prices over recent years are seeing a swing to plant oil (renewable oils) in the USA and Europe to the extent that Crambe is now classified as a new crop success (Carlson, Gardner, Hanzel. (1997). UK buyer J K Kings and Sons, has an office in North Dakota, and seeks contracts for production of Crambe to be crushed in North Dakota and shipped to UK. In this they face competition from USA firms. The price of the hulled seed (unsubsidised) is $US 135 ($250). Although the husk comprises perhaps 40 % of the biomass. Depending on the relative yields it may be not be strongly competitive with Canola if the latter is priced at more than $300 per tonne.

Despite its increasing value to industry there are some disadvantages. Farm production must be close to the industrial processing plant because of the cost of transport of the harvested seed of which up to 50 % of the weight is the lightweight husk. This takes space and makes it necessary to ensure wagons and trucks are covered to ensure no openings will leak seed.

Crambe meal itself contains 3-4% glucosinolates or about 90 mole/g of the main Brassica glucosinolate sinigrin. This is at least equal the quantity found in the yellow and brown mustards. Thus though the meal is a viable protein supplement for growing and finishing beef cattle the US Food and Drugs Administration limits its content in finishing rations to below 5 % despite recent research that it can replace up to 2/3 of the soybean meal in the control rations (Gromburger etal. 1993). Because glucosinolates are toxic to mono-gastrics, Crambe meal cannot be used for pig or poultry rations unless the glucosinolates can be removed or inactivated economically which is by no means difficult given their solubility in water.

5.3 Niger or Noog

Niger is a tropical subtropical species. It is widely cultivated in Ethiopia and grown in rotation with pulses and cereal as the summer crop. It is the prized oil of Ethiopian cuisine fetching almost double the price of mustard oils. Yields in excess of 1.5 tonnes per hectare are recorded but generally yields are less than 0.8 tonnes per hectare. It has some tolerance of poor drainage according to the local Ethiopian scientists Alemaw and Wold (1995). It is strongly crossed fertilised and requires bees for good seed production. Yields in India, the world's largest exporter, are generally around 400 kg per hectare. Niger grows rapidly in spring and early summer in Perth but it is not well adapted to Mediterranean climates other than perhaps those relatively restricted warm winter areas, which are essentially frost-free. Its main place will be Northern NSW and Queensland or areas where summer irrigation is available. Lines of Ethiopian origin were taller and later in maturity but more tolerant of cool winters than the Nepal lines assessed during the project. Highest yield was in 729 Kg of the tall growing Ethiopian 8 in the warm winter climate of Northhampton - North of Geraldton in WA. This site also had a considerable bee population attracted by the widespread stands of Paterson's Curse in the district. West of Northampton on the coastal plain, essentially frost free conditions and loamy soils may warrant future trials with the species. At other cooler winter sites where perhaps bees were less prevalent, yields were poor and often less than 100 kg per hectare.

The oil, typically around 38% content of the seed, is an attractive pale yellow in colour. With a linoleic acid content of 79% it is very similar to sunflower oil and an attractive cold pressed product. Getinet and Sharma (1996) in their booklet suggested the Indian genotypes to be lower in linoleic 56% (with a corresponding increase in oleic acid to 23%) than the Ethiopian lines. Our studies however reveal most Nepal lines to be the equivalent of the Ethiopian lines in terms of their linoleic acid but that the Nepal population did contain a set with linoleic acid content considerable lower at around 50 %, scattered in distribution through Nepal. The Nepal germplasm flowered in around 65 days 2 -3 weeks earlier than the Ethiopian germplasm and was generally more cold sensitive. The very limited germplasm base of Niger in Australia has been substantially increased through a collection mission in Nepal and some direct introductions from market samples in Ethiopia. A prolonged flowering period of 6 weeks or more leads to leafy plant of generally low harvest index and selection for improved harvest index would be a realistic aim.

Whilst it has good oil quality, there is an immediate demand in the high priced birdseed market for export to USA. For a field scale assessment 20 kg of seed was made available for farmer assessment and seed increase in NSW under the supervision of commercial partner Elders Ltd. Drought conditions have forced a delay in this program till late 2002/2003.

5.4 Evening primrose

Evening primrose oil is one of the most widely marketed dietary supplements in health shops and pharmacies. Claims are numerous for its beneficial effects on premenstrual syndrome, eczema, obesity, cholesterol, rheumatoid arthritis and vascular disorders (Caspar 1994). The benefits so claimed are presumed to be associated with its content of the essential fatty acid, Gamma Linolenic acid (GLA). Its content in the many products on sale, ranges from 8-12 percent, around half that of the content in Borage (Starflower) oil. *Oenothera spp* are naturalised and widespread in the Perth metropolitan area and 4 species were included in a survey from samples taken from Perth roadsides. They are well adapted to sandy soils, though to date under our hot summer conditions, the gamma linolenic acid content has, with the exception of one species generally been far less that the 9 percent claimed as a minimum standard for commercial evening primrose oils. Under Perth conditions the commercial Evening Primrose (*Oenothera Biennis*) produced only 8 % GLA. It is a very difficult species to harvest as it shatters badly and the pods ripen at widely differing times. At the USA price of around US$2.20/kg its profitability would be most doubtful. Due to their heritability, selection for both higher oil and GLA is feasible in naturalised populations, Brandle et al (1993). One of the members of the Evening Primrose family naturalised in Western Australia and other states, *Oenothera glazioviana* (Tall Evening primrose) produced levels in bulk samples up to 9 % GLA, suggesting a program of single plant selection should yield GLA levels of the required standard. The tall species is biennial and flowers in midsummer. The fruits of all the *Oenothera* species shatter on maturity but in this respect ‘Tall Evening Primrose’ appears to have some advantage with the upright capsules less prone to shedding seed on maturity. The species deserves further investigation as an alternative producer of evening primrose oil.

5.5 Boraginaceae

This large family features a range of cross fertilised species often used as garden plants (e.g. *Anchusa*) or herbs (Borage), whilst Echium species includes *Echium plantagineum* or Paterson’s curse (Salvation Jane) widespread as a weed in Southern Australia. In the UK Borage oil has a ready market as Starflower oil and there is an increasing demand for Echium oil. Borage oil contains double the GLA content of Evening Primrose oil. Single plant samples of wild Echium were taken only in the last season of the project and there is as yet insufficient knowledge of variation in oil content or essential fatty acids between individual plants. This will provide an attractive avenue for further research. All members of the Boraginaceae tested (including Paterson’s Curse) have proven equal to or higher in gamma linolenic acid (GLA) than the traditional source marketed as Evening Primrose oil (ca 9 % GLA). Echium also has around 10% of the anti inflammatory agent stearidonic acid a potentially very valuable product. Its oil content should be able to be improved by selection but is in keeping with UK levels. Borage itself is in demand with some 40 tones of seed being sought by New Zealand operatives in 2002. Borage grows vigorously and the seed contains 34 – 37 % oil with 19 - 25% GLA in the oil. Performance in yield trials was generally poor under our conditions. Despite yielding 455 kg/ha at one site in 2001, yields on average were less than 200 kg/ha, which may have been influenced in some sites by low populations of bees. Its strong tendency, like other members of the genus, to shatter badly and a prolonged ripening period makes it a difficult plant to manage both on a test row and larger scale. Cooler ripening conditions, e.g. as in southern Victoria or Tasmania or perhaps the south coast of Western Australia may help reduce the shattering and combined with better harvest technology including swathing (as is being tested in Tasmania in a RIRDC project) has produced very profitable yields in USA. Given a sufficient price incentive, it often sells for $US3.20 in that country. More research could be justified in terms of a crop growing best in cool summers and adequate moisture conditions (Simon et al 1990). Selection of reduced shattering lines is claimed in the UK and if successful here would be a big advantage. A limited seed increase is planned for 2003 to enable release of kilogram quantities for evaluation by farmers in cooler summer climates.

5.6 Matthiola

The common garden stock (*Matthiola incana*) was unique in its high content (65 %) of Omega 3 fatty acids. Blood Cholesterol and triglycerides were reduced by feeding seed stocks in small animal trials (Yaniv et al 1999). A perennial, a few naturalised lines have demonstrated ability to produce as an annual crop. It would be most important commercially for farmers to get a seed crop in the first year of production. Best of these was a line arising from a farmer's property. This line 'Frank Stone' appears capable of reliably setting seed in its first year of cultivation though toward mid to late summer. Harvest technology will also be important if the species is to have a place as an economical oil seed. In this context a small plot was header harvested in late 2001 with minimal seed loss. One early maturing line LO 23, selected in Israel (Yaniv, Schafferman and Shamir **1996**), performs as an annual under Perth conditions. A new line collected on the Greek Island of Samos is later, but besides its good seed set, has real potential as an ornamental plant with its attractive dual flower colour. The main disadvantages of Matthiola are the comparatively low content of oil in the seed (ca 22%) but especially its very slow early growth exposing it to weed competition. It needs sowing into weed free comparatively fertile soils.

5.7 Morama

Just 8 plants of Morama have survived 4 years at Shenton Park Research Station. A native of Botswana it is prized by people of the Kalahari Desert for the protein (32-45%) and oil content (30-42%) of its seed. The oil in its very large seeds (2-3 gm) is rich (48%) in the mono unsaturated oleic acid (Mbewe 1992). It has been the subject of postgraduate studies in Australia and Botswana by Monaghan (1995) assisted then by Botswana non Government Research Office of Thusano Lfatsheng. Vegetative growth is very vigorous during the summer months arising from a massive underground tuber. Winter dormant, it is clearly tropical and under our summer conditions has yet to set seed despite producing very large flowers. It may be that a suitable vector for the required cross pollination is not present in Perth. A promise of additional seed from Botswana following Ms Campbell's visit in 1999 has not been forthcoming but it is yet possible seed will be produced from the plants growing locally or that we should transport some corms (which now weigh several kilos), or parts thereof, to a more tropical site.

6. Implications

A program essentially akin to plant breeding will not normally allow commercial exploitation within the time frame of the current project. The plan however was to have sufficient seed, e.g. 1 tonne of the best lines available at the end of the project and at the same time provide interested parties with the seed, agronomic information and information on market potential gained from overseas contacts and any Australian experience. Sufficient seed for hectare plots of 3 lines of Niger was placed in the hands of Cotton Seed Producers, Emerald in November 2001. Likewise, seed of Crambe and Camelina was placed with commercial partner Elders Limited early in 2002. Drought conditions however have seen a need to repeat these operations in 2003. 1000 kg of seed of a species like Camelina would allow 50 tones production in the following year, the quantity suggested by English company contacts as a test market. A similar quantity 50 tonnes or more of Niger are needed for serious contact to the USA birdseed market. A Kununurra grower in part already supplies this market. These quantities of seed would also enable exploitation of the limited local markets as precursors for larger scale production

Camelina is high quality oil with considerable potential. The small local or export market for skin health preparation is immediate, but approval as a food oil in Australia has not been confirmed. An approach from a major manufacturer together with cost benefit analysis is needed. The ease of production of the oil, which does not need bleaching, would make blending with Canola to increase the Omega 3 content, a good selling point. During late 2002 an export market for the seed in the UK has emerged and contacts will be established. This likely commercial linkage arises directly following the connections made during the RIRDC supported visit of Ms M Campbell in 2002.

Crambe can readily be produced in Australia. The domestic market is as yet not well defined but specialty-lubricating oils should have a place as an industrial product. There are substantial UK imports 10,000 tonnes or more directly from USA under contract and enquiries have been received as to the possibilities of import from Australia. The opportunity for biodiesel emerges.

A naturalised plant source of evening primrose oil could well emerge from the investigations if 2003 oil data confirms previous results.

7. Recommendations

Links need to be established with a producer of edible oil and a market analysis on the value of Camelina conducted. Immediate UK markets do exist for Crambe and Camelina. Formal links need to be established with one of the UK firms marketing these and other species as defined in the visit of Ms Campbell in 2002. (Report M Campbell 2002). Contacts have been maintained but should be formalised once the seed increase plans now rescheduled for 2003 are successfully implemented by Elders. The impact of Niger will depend on the performance in Northern NSW and Queensland for which arrangements are in hand. Current structure of commercial partner Elders well suited to seed supplies and export and stimulation of production per se. During the course of the project, the commercial partner found a market for 40 tonnes of Borage. This would need to be investigated by production in Tasmania or perhaps southern Victoria.

There is also a clear market for Evening Primrose oil. The project has defined a locally adapted species with very promising levels of gamma linolenic acid (GLA), which certainly warrants further research and development. Discussion with marketers of the current range for which the oilseed is imported note the seed or oil arises largely from China.

8. Appendices

8.1 Appendix 1 - Alternative oilseed germplasm

Table 15. Alternative Oilseed germplasm on hand at termination of project

Species	No Lines	Source
Borago officinalis	6	Various commercial outlets
Camelina sativa	1	Australian Temperate Field Crop Collection.
Camelina sativa	97	Vavilov Institute, Russia
Camelina sativa	1	Camelina Pty Ltd, Finland
Crambe abyssinica	8	Australian Temperate Field Crop Collection.
Crambe abyssinica	24	Vavilov Institute, Russia
Giuzotia abyssinica	84	Nepal collection, Jon Clements
Giuzotia abyssinica	8	Ethiopia, Clive Francis
Giuzotia abyssinica	12	Vavilov Institute, Russia
Giuzotia abyssinica	6	USDA
Giuzotia abyssinica	3	Nepal
Matthiola incana	18	Israel
Matthiola incana	14	Nedlands garden
Matthiola incana	6	Perth coast
Matthiola incana	1	Samos
Morama	3	Brian Monaghan
Oenothera drummondii	3	Collection round Perth and South East WA
Oenothera glazioviana	4	Collection round Perth and South East WA
Oenothera mollisima	3	Collection round Perth and South East WA
Oenothera stricta	4	Collection round Perth and South East WA
Oenothera biennis	4	Collection round Perth and South East WA

8.2 Appendix 2 - Site details

Table 16. Site details

Site Name	Abbreviation	Location	Mean Rainfall	Soil Type
UWA Research Station	FS	31.9 S, 115.8 E	865	Sandy loam, pH 6.5
Meckering	Meck. or M	31.6 S, 117.1 E	402	Loamy sand, pH 5.5
Merredin	Mrrdin	31.5 S, 118.3 E	328	Sandy, pH 5
Miling	Miling	30.5 S, 116.2 E	405	Gravelly sand, pH 5.5
Mingenew	Mgnew	29.1 S, 114.5 E	380	Loam, pH 6.0
Northam	Northam	31.6 S, 116.7 E	432	Gravelly S/loam, pH5.5
Northampton	Northn or N	28.5 S, 114.1 E	452	Loam, PH 6.5
Screen House, Perth	S/H	31.9 S, 115.8 E	Irrigation	Sandy, pH 6.0
Wagin	Wagin or W	33.3 S, 117.3 E	438	Gravelly duplex, pH 5.0

8.3 Appendix 3 - Genetic variation in Camelina

Table 17. Details of the range within the characteristics of the different lines grown in a common garden at the UWA Research Station in Perth WA

Line No	% Oil	% Oleic	% Linoleic	% Linolenic	% Eicosenoic	% Erucic	Wt. 1000 seeds
4059	36.7	13.46	18.26	35.82	14.76	3.54	0.83
4062	36.3	15.12	18.68	34.0	15.24	3.56	0.81
4076	38.9	14.73	17.81	33.82	15.77	3.47	0.83
4077	35.4	13.76	17.09	34.51	15.8	3.75	0.93
4111	35.8	13.12	18.71	34.75	15.0	3.5	0.94
4112	35.8	13.46	19.11	34.83	14.2	3.57	0.79
4130	36.3	15.75	20.34	34.57	13.5	2.45	0.94
4131	32.9	13.71	19.48	34.65	14.0	3.14	0.96
4132	37.6	14.24	17.95	34.77	14.9	3.71	0.89
4136	37.4	14.94	17.48	33.79	16.0	3.74	0.91
4138	37.1	16.54	18.8	31.18	15.7	3.29	0.87
4147	36.3	13.2	18.27	34.24	15.3	3.49	1.09
4164	38.6	13.93	19.53	31.36	15.8	3.97	0.97
4175	35.0	12.88	17.79	35.76	15.1	3.77	0.87
4176	38.3	12.36	18.14	34.08	16.1	3.9	1.07
4177	38.7	15.03	18.35	32.75	15.5	3.38	0.93
4183	37.3	13.88	15.88	35.65	16.2	4.17	0.82
4184	37.9	15.24	18.83	33.56	14.8	3.15	0.99
4185	34.8	14.11	17.9	33.77	15.8	3.4	0.81
R1357	36.3	13.87	19.74	31.35	15.9	4.0	0.92
R1993	35.1	13.52	16.83	34.01	16.7	4.21	1.61
R339	37.9	18.65	15.14	33.15	16.46	3.31	0.66
R349	36.4	13.16	18.87	33.62	15.38	3.93	0.92
R370	34.9	14.3	18.44	35.11	14.96	3.16	0.94
R4068	39	14.55	18.24	33.86	15.18	3.41	0.88
R4074	37.3	15.88	18.49	33.39	14.93	3.14	0.92
R4148	36.7	16.19	18.59	33.79	14.77	3.16	1.08
R4164	36.3	14.94	16.09	33.57	16.69	4.13	1.04
R4175	36.1	12.56	22.52	32.99	14.21	3.26	0.74
R4182	33.1	13.93	16.47	36.94	15.41	3.49	0.96
R4183	34.7	14.32	17.4	34.14	16.22	4.14	0.81
R4185	37.1	15.56	17.26	34.95	16.18	3.58	0.75

8.4 Appendix 4 - Fatty acid profiles of Crambe

Table 18. Details of the fatty acid profiles of 21 lines of Crambe grown in Perth WA in 2001

Line	% Saturated	% Oleic	% Linoleic	% GLA	% Omega 3	% Erucic
K1	2.6	14.3	8.8	5.1	3.1	61.6
K2	2.6	14.2	7.9	6.1	2.6	62.1
K4	2.2	14.0	7.9	6.1	2.2	63.2
K5	2.2	14.0	8.0	6.1	2.3	62.7
K6	2.3	14.5	7.6	6.1	5.5	62.1
K7	2.3	14.0	8.1	6.0	2.4	62.5
K8	2.2	14.2	7.9	6.0	2.4	62.9
K11	2.1	14.0	8.0	6.3	2.2	63.0
K14	2.7	19.1	8.2	6.3	5.1	54.6
K21	2.3	13.4	8.3	5.8	2.6	62.8
K25	2.2	13.8	8.1	6.2	2.3	63.3
K26	2.2	14.2	7.9	6.1	2.4	62.5
K27	2.2	14.1	7.8	6.1	2.1	62.8
K28	2.2	13.8	7.8	5.9	2.3	63.4
K31	2.2	14.2	7.7	5.0	2.3	63.2
K32	2.1	13.5	8.3	6.2	2.0	63.2
K35	2.3	14.1	8.1	6.1	2.6	62.1
K39	2.5	14.1	8.3	6.3	2.8	61.1
K40	2.3	13.7	8.5	6.1	2.7	61.7
K42	2.4	14.8	8.4	5.0	3.6	61.0
K43	2.2	14.2	7.6	5.9	2.5	62.9

8.5 Appendix 5 – Origin and fatty acid profile of Niger

Table 19. Details of the origin and fatty acid profiles of 44 lines of Noog or Niger grown in Perth WA in 1999

Line	Origin	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid
G3	Nepal	9.6	7.8	6.7	73.7
G5	Nepal	9.6	7.1	6.8	75.0
G6	Nepal	14.0	9.1	5.7	55.0
G9	Nepal	9.8	7.8	7.5	73.0
G11	Nepal	18.1	8.1	8.1	56.5
G17	Nepal	20.8	5.3	8.3	50.3
G19	Nepal	9.4	7.4	6.5	75.0
G20	Nepal	8.1	5.5	3.8	48.0
G21	Nepal	14.0	12.1	8.5	51.5
G25	Nepal	13.9	7.1	4.9	74.4
G29	Nepal	10.7	8.7	6.4	72.0
G35	Nepal	10.8	8.3	7.2	72.0
G39	Nepal	16.5	13.5	8.4	55.0
G41	Nepal	17.2	13.6	5.5	54.0
G43	Nepal	9.9	7.4	7.0	73.0
G45	Nepal	15.7	11.9	8.1	62.0
G49	Nepal	17.9	13.9	8.2	66.0
G51	Nepal	24.4	20.8	9.1	42.0
G53	Nepal	9.7	7.9	8.1	45.0
G55	Nepal	30.7	24.5	10.0	30.0
G57	Nepal	11.7	9.9	7.8	69.0
G59	Nepal	30.3	22.6	8.3	33.8
G61	Nepal	17.0	13.1	12.4	54.0
G63	Nepal	13.6	10.6	9	64.0
G65	Nepal	18.3	12.4	9.3	57.0
G69	Nepal	10.2	7.6	7.3	72.0
G71	Nepal	14.7	10.3	7.6	65.0
G75	Nepal	9.6	7.0	7.3	74.0
G77	Nepal	13.4	10.2	8.6	65.0
G79	Nepal	20.0	14.9	9.1	53.0
G81	Nepal	9.9	7.5	8.4	72.0
G83	Nepal	14.0	10.4	8.2	65.0
G85	Nepal	10.2	11.5	4.7	65.0
G89	Nepal	9.7	5.1	7.8	77.0
Nepal 1	Nepal	8.6	7.2	10.1	72.7
Nepal 2	Nepal	8.8	7.5	11.3	70.0
Eth N1	Ethiopia	9.3	6.6	7.8	74.0
Eth N2	Ethiopia	9.5	6.5	9.5	73.1
Eth N5	Ethiopia	9.2	6.6	7.4	75.2
Eth N8	Ethiopia	8.8	6.7	7.1	75.4
Bagmatti	Nepal	8.3	7.0	5.7	77.1
Ramtil 7	Poland	8.3	8.4	18.2	63.3
Ramtil 14	Spain	8.3	6.7	14.9	68.7
Ramtil 41	Portugal	8.8	7.6	8.6	73.4

8.6 Appendix 6 – Management information for alternative oilseeds

This information is a guide to help in the bulking of some of the Alternate Oilseed lines.

Table 20. General information for Crambe and Camelina

Seeding	Depth	1 – 1.5 cm
	Spacing	7 – 9 inch rows
	Press Wheels	Will improve establishment
	Method	Full-cut or min-till can be used
Fertilizer	Prior to seeding	Apply 50 kg/ha muriate of Potash
	At seeding	Apply a compound fertilizer with trace elements (e.g. Agstar plus) at 80 kg/ha.
		Can be deep banded or sown with the seed. Preference is for deep banding.
	3 weeks later	Apply 50 kg/ha Urea.
Root disease	If site suspect	A fungicide in furrow treatment of Impact or Triad is desirable.
Insect control	Red-legged earth mites.	An application of Talstar soon after seeding is advised.
	Other insects	Any insecticides are OK but should be used on their own.
		Use spraying thresholds as for Canola.
Weed control	At seeding	Apply a knockdown e.g. Roundup or Sprayseed at seeding.
	At seeding	Use Treflan at 1 L/ ha to control grasses under min-till
	Post–em grass control	Fusion 500 gm, Fusilade at 1 L or Verdict at 80 ml/ ha
Harvesting	Even maturity	Should be harvested within two weeks of ripe harvest stage

Table 21. Specific treatments for the different species

Item	**Sowing rate**	**Broadleaf Weed control**	**Harvester Setting**
Camelina	5 kg/ha	Lontrel (300 ml/ha) or Spinnaker at 100 ml/ha, but not in a mixture.	As for Canola, but keep the airflow down due to small seed size.
Crambe	12 kg/ha.	Lontrel (300 ml/ha) or Buctril 200 at 150 ml/ha, but not in a mixture.	As for canola, adjust accordingly to minimize shattering of the fruit; keep the airflow down due to the light weight of the fruit.

8.7. Appendix 7 - Management information for each species

1. *Camelina sativa* (False Flax or Camelina)

Seeding:

The seed is small i.e. between 800 and 1400 seeds to a gram.
Sowing rate is about 5 kilograms per hectare. Can be sown into dry soil.
Sowing depth 1 cm – 1.5 cm. Full-cut or min-till can be used.
Press wheels will improve establishment.
Row spacing 7 – 9 inches.

Fertilizer:

Prior to seeding 50 kg/ha of muriate of Potash top-dressed.
At sowing apply a compound fertilizer with trace elements (e.g. Agstar plus) at 80 kg/ha. Can be deep banded or sown with the seed. Preference is for deep banding.
Three weeks after seeding apply 50 kg/ha Urea.

Root disease control:

Little is known about tolerance to root disease, if the site is suspect for root disease then a fungicide in furrow treatment of Impact or Triad is desirable.

Weed control:

Apply a knockdown e.g. Roundup or Sprayseed at seeding.
Use Treflan at 1 L/ ha to control grasses under min-till.
For post –em grass control, Fusion 500 gm, Fusilade at 1 L or Verdict at 80 ml/ ha have been used successfully.
For broad leaf weed control the options are limited; Lontrel (300 ml/ha) has been used successfully after the 4 leafed stage of growth of the crop to control capeweed and Buctril 200 at 150 ml/ha is also OK but not as part of a mixture.

Insect control:

Any Insecticides, but should be used on their own. An application of Talstar soon after seeding is advised to control red legged earth mites. Camelina appears to be tolerant of insects with little damage. Use spraying thresholds as for Canola.

Harvesting:

Even maturity, should be harvested within two weeks of ripe harvest stage.

Harvester settings:

Use settings as for canola adjust accordingly, but keep the airflow down due to small seed size.

Control of regrowth:

There is little dormancy in the seeds and 95% of the seed will germinate with the first rains. Normal knockdown rates of Roundup and Sprayseed will eliminate seedlings. Applications of Atrizine will also control regrowth. And a spike of group B herbicides will give residual control. Post-emergent herbicides that can be used include Raptor, Spinnaker, Tigrex and Diuron.

2. *Crambe abyssinica* (Crambe)

Seeding:
The seed is sown with its fruit coat and so is larger and lighter than normal.
Sowing rate is about 12 kilograms per hectare. Can be sown into dry soil.
Sowing depth 1 cm – 1.5 cm. Full-cut or min-till can be used.
Press wheels will improve establishment.
Row spacing 7 – 9 inches.

Fertilizer:
Prior to seeding 50 kg/ha of muriate of Potash top-dressed.
At sowing apply a compound fertilizer with trace elements (e.g. Agstar plus) at 80 kg/ha. Can be deep banded or sown with the seed. Preference is for deep banding.
Three weeks after seeding apply 50 kg/ha Urea.

Root disease control:
Not known to be susceptible to blackleg little is known about tolerance to other root of leaf diseases, if the site part of a close rotation then a fungicide in furrow treatment of Impact or Triad may be desirable.

Weed control:
Apply a knockdown e.g. Roundup or Sprayseed at seeding.
Use Treflan at 1 L/ ha to control grasses under min-till.
For post –em grass control, Fusion 500 gm, Fusilade at 1 L or Verdict at 80 ml/ ha have been used successfully.
For broad leaf weed control the options are limited. Lontrel (300 ml/ha) has been used successfully after the 4 leaf stage of the crop to control capeweed and Spinnaker at 100 ml/ha is also OK but not as part of a mixture.

Insect control:
Any insecticides can be used but should be used on their own. An application of Talstar soon after seeding is advised to control red-legged earth mites. Crambe appears to be tolerant of insects with little damage. Use spraying thresholds as for Canola.

Harvesting:
Even maturity, Fruit can be prone to dropping off the plant (dehiscing) so should be harvested within one week of ripe harvest stage.

Harvester settings:
Use settings as for canola, adjust accordingly to minimize shattering of the fruit, but keep the air flow down due to the relatively light weight of the fruit.

Control of regrowth:
There is little dormancy in the seeds and 95% of the seed will germinate with the first rains. Normal knockdown rates of Roundup and Sprayseed will eliminate seedlings. Applications of Atrizine will also control regrowth. And a spike of group B herbicides will give residual control. Post-emergent herbicides that can be used include Brom MA, and Tigrex.

3. *Giuzotia abyssinica* (Niger or Noog)

Seeding:

A tropical/subtropical species, it requires warmth for best yields. It can be sown in spring in areas with a Mediterranean type climate and yield if there is sufficient stored moisture. But if soil moisture is limited, irrigation may be required.
Sowing rate is about 5 kilograms per hectare.
Sowing depth 1 cm – 1.5 cm. Full-cut or min-till can be used.
Press wheels will improve establishment.
Row spacing 7 – 9 inches.

Fertilizer:

Prior to seeding 50 kg/ha of muriate of Potash top-dressed.
At sowing apply a compound fertilizer with trace elements (e.g. Agstar plus) at 80 kg/ha. Can be deep banded or sown with the seed. Preference is for deep banding.
Three weeks after seeding apply 50 kg/ha Urea.

Root disease control:

Little is known about tolerance to root disease, if the site is suspect for root disease then a fungicide in furrow treatment of Impact or Triad is desirable.

Weed control:

Apply a knockdown e.g. Roundup or Sprayseed at seeding.
Use Treflan at 1 L/ ha to control grasses under min-till.
For post –em grass control, Fusion 500 gm, Fusilade at 1 L or Verdict at 80 ml/ ha have been used successfully.

Insect control:

Any Insecticides, but should be used on their own. An application of Talstar soon after seeding is advised to control red legged earth mites. Niger appears to be tolerant of aphids with little damage. Use spraying thresholds as for Safflower or Sunflowers.

Harvesting:

In Nepal and India, the crop is swathed when the seed heads turn black. It is then threshed when crop is dry. In large plot trials in WA during the project, the crop was directly harvested when the seed heads were dry with a conventional harvester.

Harvester settings:

Use settings as for canola adjusted accordingly.

Control of regrowth:

There is little dormancy in the seeds and 95% of the seed will germinate with the first rains. Normal knockdown rates of Roundup and Sprayseed will eliminate seedlings. Applications of Atrizine will also control regrowth. And a spike of group B herbicides will give residual control. Post-emergent herbicides that can be used include Lontral, Butril 200, Brom MA and Cadence.

9. Bibliography/references

a) Publications arising

Campbell M C, Francis C M, Kailis S G, Clements J C, and Milton J T. (1999). Some exotic oil seeds with fodder potential. Proceedings Eucarpia Conference, St Petersburg 1999.

Campbell M C (2002). A travel report presented to RIRDC

Clements Jon, Mishra B, Francis C M, Neupane R K, Francis D S, Campbell M C, (2000) Collection and ecogeography of Niger (*Guizotia abyssinica*) in Nepal. IPGRI Newsletter

Francis C M, Campbell M C, Clements J C (1999) New crops and oilseeds from Ethiopia and elsewhere. Australian New Crops Newsletter No 11

b) References

Alemaw G and Wold A T (1995) An agronomic and seed quality evaluation of Noog (Guizotia abyssinica) Plant Breeding 114:375

Brandle J E, Court WA, and Roy R C (1993). Heritability of seed yield, oil concentration and oil quality among wild biotypes of Ontario Evening Primrose. Canadian Journal of Plant science 73:1067-1070.

Carlson K D, Gardner J C, Hanzel J (1997). Crambe a new crop success. New Crops 12:306

Caspar W K (1994). Primrose oil in the treatment of premenstrual disphoric disorder: is the bloom off the rose? Psych Ann 24:255-258

Crowley J G and Frohlich A (1998). Factors effecting the composition and uses of Camelina TEAGASC publication ISBN 1 901138 66 6

Getinet A, and Sharma S M (1996). Niger. IPGRI Booklet ISBN 92-9043-292-6 58 pages

Galway N W and Shirlin A J (1990) Selection of Borage (*Borago officinalis*) as a seed crop for pharmaceutical uses. Heredity 65:249-247

Grombacher A, Nelson L, Baltensperger D. Crambe Production (1993). In Field Crops File G1126 University of Nebraska Extension Services.

Hubbard A (1998) Camelina Sativa – a pleasurable experience or another false hope. Lipid technology, July Pp 81 –83

Jimenez De Blas O, and Gonzalez A D V. (1996). Gas chromatographic differentiation of virgin, refined and solvent-extracted olive oils. Journal of AOAC Int. 79: 3 pp 707-709.

Knights S E (2002) Crambe: A North Dakota Case Study A report for the Rural Industries Research and Development Corporation By SE Knights February 2002 RIRDC Publication No W02.

Korsrud G O, Keith M O, and Bell J M. (1978). A comparison of the nutritional value of Crambe and Camelina seed with egg and casein. Can. J. Animal. Sci.

Lazzari L, Leoni O, Conte L S and Palmieri S (1994) Some technological and potential uses of *Crambe abyssinica* products. Industrial Crops and Products 3: 103-112

Lange R W, Schumann M, Petrika H, Busch H and Marquand R (1995). Glucosinolates in linseed dodder. Fat Sci. Technology

Lovett J V and Duffield A M 1981). Allelo chemicals in Camelina sativa.
J. Appl. Ecol. 18:283

Mbewe M N (1992). The domestication of Morama beans (Tylosema esculentum Proceedings international Conference on the development of new crops, Jerusalem, Israel 8 March 1992

Monaghan B G (1995) Genetic variation in Morama bean (Tylosema esculentum) Australian Field Crops Newsletter No 4 Chapter 20

Putman D H, Budin J T, Field L A, and Breene W M. (1983) Camelina a promising low input oilseed. In Janik and Simon J Eds. New Crops. Wiley, New York.

Simon J E, Beaubaire N, Weller S C, Janick J (1990) Borage a source of gamma linoleic acid. P 528 In Advances in new crops. Janick J and Simon JE Eds. Timber Press Portland USA

Yaniv Z, Schafferman Zur M, and Shamir I (1996). *Matthiola incana* : Source of Omega –3-linolenic acid p 368-372 in J Janick ed. Progress in new crops ASHS Press Arlington VA

Yaniv Z, Schafferman Zur M, Shamir I and Zecharia M (1999). Cholesterol and triglyceride reduction in rats fed Matthiola incana seed rich in (n-3) fatty acids. Journal of Agricultural and Food Chemistry 47: 637-642