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Bevan Buirchell

Wallace Cowling

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Domestication of rough-seeded lupins

By Bevan Buirchell, Research Officer and Wallace Cowling, Plant Breeder, Crop Industries, South Perth

Since the beginning of civilisation, humans have been domesticating wild plants such as wheat, barley and rice. They have both consciously and unconsciously selected plant types suited to cropping.

Recently, there has been an increasing effort to domesticate a greater variety of wild plants, especially legumes.

Peasants in southern Europe, northern Africa and South America have cultivated lupins for thousands of years. They selected plants that had non-shattering pods and seeds that germinated readily, however, all plants had bitter seed that had to be boiled and soaked before it could be eaten.

John Gladstones led the world in producing fully domesticated varieties of the sweet-seeded, narrow-leafed lupin, Lupinus angustifolius, in Western Australia. The rotation of L. angustifolius and cereals provides a productive and stable cropping system on acid, sandy soils.

Unfortunately, L. angustifolius is poorly adapted to the four million hectares of alkaline or fine textured soils in Western Australia, and apart from a small area of field peas, grain legumes are not grown on these soils.

Plant breeders are domesticating two species of rough-seeded lupins that are well adapted to fine textured or alkaline soils.
Rough-seeded lupins, so-called because of their rough seed coats, are a group of seven closely related lupin species.

Many rough-seeded lupins grow naturally on alkaline or fine textured soils in diverse environments of the Mediterranean and north African regions.

The domestication of these species may improve farmers’ choices of grain legumes in crop rotations on these soil types in Western Australia.

**L. atlanticus**
Found exclusively in the Atlas and Anti-Atlas Mountains of Morocco, *L. atlanticus* grows on stony schistose and granitic soils with neutral to alkaline pH. This species extends into altitudes of 1500 m or more, in areas with a short winter and spring growing season. *L. atlanticus* grows in some of the driest cultivated areas of Morocco (as low as 250 mm rainfall), and thus demonstrates some drought resistance.

**L. pilosus**
*L. pilosus* is found at the eastern end of the Mediterranean basin, in the Greek islands, Turkey, Syria and Israel. This species grows on fine textured soils in moderate rainfall areas and it tolerates more free lime in the soil than most other lupin species, except *L. cosentini.*
lupins

*L. digitatus*

*L. digitatus* is reported to be a 'desert ephemeral' or short-lived opportunistic species. This species is distributed across the central and western Sahara, indicating that it may be drought resistant or drought evasive. The species may be the only lupin species of the Mediterranean and north African regions that flowers rapidly in response to longer days. It also has some cold requirement for rapid flowering. Only one variety exists in world seed banks.

![L. digitatus flowers and seeds.](image)

*L. cosentinii cv Erregulla-S seeds.*

*L. cosentinii*

*L. cosentinii* originates from the coastal plains of Morocco and Portugal. This species has been naturalised in Western Australia for many years and grows successfully on the coastal plain between Bunbury and Geraldton. John Gladstones produced fully domesticated *L. cosentinii* varieties, called Erregulla (hard-seeded) and Erregulla-S (soft-seeded). These varieties are suited to the coastal plain where frosts are rare and temperatures during the growing season are relatively warm.

![L. cosentinii flowers and seeds.](image)

*L. albus cv Kiev mutant seeds.*

*L. princei*

*Originating from north-east tropical Africa, Kenya, Tanzania and southern Ethiopia, L. princei grows at altitudes of about 2000 m, where the rainfall is moderate and the growing season is long. Consequently, this species flowers after more than 150 days after sowing in Western Australia. It requires a specific rhizobium strain for nodulation and does not nodulate with the standard strain used for all lupin species in Australia.

![L. princei flowers and seeds.](image)

*L. angustifolius cv Gungurru seeds.*

*L. somaliensis*

*L. somaliensis* was originally collected in 1895 from the highlands of Somalia. Today, it may be extinct in its native environment or present as a variation of *L. princei.*

![L. somaliensis flowers and seeds.](image)
From wild lupin to crop plant

Four major characteristics have to be introduced into wild lupins to produce a plant suitable for cropping with modern techniques.

Soft seededness

Wild lupins have ‘hard seeds’ that do not absorb water until the waxy layer on the seed coat has degenerated or been abraded by some means. This may take several years. By keeping a reserve of ungerminated seed in the soil, the wild species survive seasons when seed production may be poor. In a modern farming system, complete germination is required after planting – crops are selected for ‘soft seeds’ that absorb water and germinate when in contact with moisture.

Non-shattering pods

When the pods of wild lupins ripen, they shatter, spreading the seeds away from the parent plant. In modern agriculture, grain is harvested by machine, and lupins must retain their seed in their pods until harvest.

Sweet seededness

As a protective mechanism against some pests and grazing animals, wild lupins produce bitter alkaloids in their leaves and seeds. The alkaloid content of wild lupins needs to be reduced, so that the seed is no longer unpalatable to humans or animals, that is, it is sweet seeded.

Early flowering

Most wild lupins require exposure to cold temperatures before they produce flowers. This allows them to synchronise their flowering with the seasons in their native habitat. Because Western Australia has a short and relatively warm growing season, the cold requirement has to be removed so that the lupins flower and set seed before the onset of the early summer drought.

The Australian lupin industry is based on the pioneering selections and breeding of John Gladstones, which started in 1954 (see Journal of Agriculture articles in Vol. 23 (3) pp 67-76, 1982). Fully domesticated varieties of *L. angustifolius* were first released in Western Australia in 1987.
### Average whole seed composition (per cent dry matter) in different *Lupinus* species

<table>
<thead>
<tr>
<th>Species</th>
<th>% Crude protein</th>
<th>% Oil</th>
<th>% Fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>L. angustifolius</em></td>
<td>34</td>
<td>6</td>
<td>36</td>
</tr>
<tr>
<td><em>L. albus</em></td>
<td>39</td>
<td>11</td>
<td>-</td>
</tr>
<tr>
<td><em>L. cosentinii</em></td>
<td>38</td>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td><em>L. atlanticus</em></td>
<td>29</td>
<td>4</td>
<td>42</td>
</tr>
<tr>
<td><em>L. pilosus</em></td>
<td>26</td>
<td>5</td>
<td>42</td>
</tr>
<tr>
<td><em>L. palaestinus</em></td>
<td>33</td>
<td>4</td>
<td>34</td>
</tr>
<tr>
<td><em>L. digitatus</em></td>
<td>37</td>
<td>-</td>
<td>33</td>
</tr>
<tr>
<td><em>L. princei</em></td>
<td>38</td>
<td>-</td>
<td>24</td>
</tr>
</tbody>
</table>

(cv Uniwhite). Modern varieties, such as Gungurru, are only one or two generations away from their wild parents.

All the domesticated characteristics have been incorporated into five lupin species:

- *L. angustifolius* (narrow-leafed lupin)
- *L. albus* (white lupin)
- *L. luteus* (yellow lupin)
- *L. cosentinii* (sandplain blue lupin)
- *L. pilosus* (tarwi or South American lupin)

### *L. pilosus* and *L. atlanticus*

In 1979, John Gladstones described a new rough-seeded lupin species from Morocco, *L. atlanticus*. Recognising the potential of this species and its close relative *L. pilosus*, both of which are adapted to fine-textured soils with neutral to alkaline pH, he initiated attempts to domesticate these species. This breeding work has progressed considerably under the authors of this article, Bevan Buirchell and Wallace Cowling, and among other things has led to the discovery of the world's first 'sweet' mutant plant of *L. pilosus* (see 'Sweet success' on page 137).

**Growth patterns**

Wild varieties of *L. atlanticus* remain as a small rosette of leaves for about 10 weeks after sowing. With the onset of warm and long spring days, *L. atlanticus* grows quickly and flowers about 100 days after planting (compared with 75 to 80 days in *L. angustifolius* cv Gungurru).

Despite the late flowering time, *L. atlanticus* matures rapidly and can be harvested at the same time as Gungurru. This rapid maturation makes this species suited to the eastern wheatbelt, where water rapidly becomes limiting at the end of the season.

Wild types of *L. pilosus* have a similar growth habit to *L. albus* (such as Kiev mutant). *L. pilosus* grows quickly, flowers early (75 to 90 days) but takes a long time to mature. The slow maturity is probably related to its large seed size and thick pod walls, which take time to develop and ripen. This species grows well in most environments, but seems to suit areas with long seasons that allow for its slow maturity.

### Domestication

The domestication and development of a rough-seeded lupin for modern agriculture depends greatly on the availability of genetic diversity. The lupin collection at the Department of Agriculture has the most comprehensive collection of *L. atlanticus* (56 accessions) and *L. pilosus* (90 accessions) in the world, and yet it only represents a small amount of the genetic diversity in these species.

Three sources of the domesticated genes are used in lupin breeding programs:

- mutants from wild populations (used for the sweet, soft seededness and shatter resistant genes in *L. angustifolius*);
- artificial mutations caused by chemicals or radiation (used for the sweet seeded gene in *L. cosentinii*); and
• previously domesticated lupins that are closely related to the wild lupins – interspecies crossing.

Domesticated genes are being bred into L. atlanticus and L. pilosus from all three sources.

Soft seededness
The natural soft seededness of L. pilosus varies between 10 and 70 per cent from year to year in the same line. The natural soft seededness of L. atlanticus is consistently less than 10 per cent.

Soft seededness appears in the progeny of interspecies crosses between L. atlanticus and L. cosentinii and there are now several hybrid lines with soft seed. A recent mutation program has resulted in five lines that have complete soft seededness in L. pilosus and one line in L. atlanticus.

Non-shattering pods
Shatter resistance genes were found in natural mutants of L. angustifolius and L. albus, however, the only rough-seeded lupin species with shatter resistance is L. cosentinii cv Erregulla.

Interspecific crossing is being used to transfer the shatter resistance genes from the domesticated form of L. cosentinii into L. atlanticus. The hybrids between these species are viable, however, their pods shatter. Continued back-crossing to L. cosentinii has transferred the shatter resistance genes to the progeny. Unfortunately, the plants produced from the back-crossing resemble L. cosentinii and are not very productive.

The progeny of a recent mutation program are being screened for shatter resistance. Four mutant lines of L. atlanticus are showing signs of shatter resistance.

Sweet seededness
Rough-seeded lupins have different alkaloids from those in L. angustifolius and L. albus, and special tests are needed to accurately measure these compounds. The alkaloid levels in the seed of wild rough-seeded lupins are about a fifth of those in wild L. angustifolius, but are still too high for animal or human consumption.

Following a mutation program, several lines were selected from L. atlanticus that have low alkaloid levels in the foliage and seed. These mutated lines have been used in a crossing program to transfer the sweet seeded gene into other lines. Additional mutation breeding is searching for low alkaloid genes in L. pilosus.

Early flowering
Early flowering types were required in L. angustifolius to match the short growing season in Western Australia. With L. atlanticus’s rapid maturity, the incorporation of early flowering would allow this species to grow in low rainfall areas.

While there are no such wild types in the collection, early flowering has been incorporated into L. atlanticus through interspecies crossing with L. digitatus. The primary hybrid has lost the cold requirement of L. atlanticus
and flowers 20 to 30 days earlier than the parents. Further crossing and backcrossing have resulted in a \textit{L. atlanticus} type that flowers 75 to 90 days after sowing.

\textit{L. pilosus} is naturally early flowering, and most wild types do not have a cold requirement.

**Results of field trials**

Over the past four years the yield potential and suitability of \textit{L. atlanticus} and \textit{L. pilosus} lines were tested in several different areas in Western Australia. In small plot trials on fine textured soil types, \textit{L. atlanticus} out-yields \textit{L. albus} and \textit{L. angustifolius} at Chapman Valley. In the long growing season at Mt Barker, \textit{L. pilosus} out-yields \textit{L. albus} and \textit{L. angustifolius}.

\textit{L. atlanticus} can set up to 30 pods on the main stem inflorescence. Secondary pod set is also prolific if the season is long.

\textit{L. pilosus} has fewer flowers on the main stem and, consequently, sets fewer pods (up to 15) than \textit{L. atlanticus}. Being earlier flowering than \textit{L. atlanticus}, \textit{L. pilosus} is capable of setting secondary pods in most areas, however, the season must be long enough to allow these slow maturing pods to ripen.

**Seed composition**

Both \textit{L. atlanticus} and \textit{L. pilosus} have protein levels lower than \textit{L. angustifolius} or \textit{L. albus} (see Table). This is probably due to the thick seed coat of these species that accounts for a large percentage of the total seed weight.

The oil contents are low in \textit{L. atlanticus} and \textit{L. pilosus} but equivalent to \textit{L. angustifolius}. \textit{L. atlanticus} has a high proportion of fibre in the kernel, which may be important in human diets.

**The future**

Much progress has been made toward transferring all four domesticated characteristics into \textit{L. atlanticus}. Shatter resistance is yet to be incorporated into \textit{L. pilosus}.

Although domesticking wild plants is a slow process, farmers can expect the release of new lupin species that are adapted to alkaline and fine textured soils, within the next 7 to 12 years.

**Acknowledgements**

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**Sweet success**

The world’s first ‘sweet’ mutant plant of the rough-seeded lupin species \textit{L. pilosus} has been discovered in Western Australia’s lupin breeding program.

In October 1992, scientist Bevan Buirchell found a low alkaloid mutant plant in a population of \textit{L. pilosus} which had been chemically mutated during the breeding program in 1991.

This ‘sweet’ mutation is one of the four major changes that are necessary in the domestication of wild lupin species before they can be established as an agricultural crop species.

This single mutant plant puts Western Australia’s breeding team one step closer to domesticking a lupin species that is well adapted to fine textured soils and can tolerate soils of alkaline pH with high free lime content.

The particular plant became a ‘celebrity’ and was given special care. It was covered with mesh to protect it from insects and animal predators. As well, the plant was watered regularly into November so that it would set more seed in what normally is the finish of the season for most lupin plants.

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Bevan Buirchell with the protected lupin plant.