Domestication genes in narrow-leafed lupin

Matthew Nelson, Dini Ganesalingham and Wallace Cowling
International Centre for Plant Breeding Education and Research (ICPBER), The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia.

Mutations in specific major-effect genes confer a suite of traits that make narrow-leafed lupin suitable for cultivation as a crop.

Narrow-leafed lupin (Lupinus angustifolius) is an important grain legume crop in southern Australia and plays an important role in international agriculture (Gladstones et al. 1998). The ability to fix nitrogen via symbiosis with Bradyrhizobium in root nodules is valuable in crop rotations. Lupins are highly self-pollinating diploids and most natural populations are composed of near-homozygous individuals.

Narrow-leafed lupins are unique among crop plants in having been domesticated for agriculture in the twentieth century (Cowling et al. 1998). The domestication of narrow-leafed lupin has involved the introduction of key domestication traits controlled by mostly recessive mutations at five or six loci (Table 1) (Cowling 1999, Gladstones 1970, Nelson et al. 2006).

Table 1. Important domestication genes of narrow-leafed lupin (adapted from Gladstones, 1970).

<table>
<thead>
<tr>
<th>Domestication trait</th>
<th>Characteristic</th>
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<tbody>
<tr>
<td>leucospermus (leuc)</td>
<td>Seeds with white background and various degrees of brown marbling</td>
</tr>
<tr>
<td>mollis (moll)</td>
<td>Permeable seed coat</td>
</tr>
<tr>
<td>lentus (le)</td>
<td>Reduced pod shattering [accompanied by red pigment in cortex of lower stem and inside pod walls]</td>
</tr>
<tr>
<td>tardus (ta)</td>
<td>Reduced pod shattering</td>
</tr>
<tr>
<td>iucundus (iuc)</td>
<td>Low alkaloid</td>
</tr>
<tr>
<td>Ku</td>
<td>Dominant early flowering [removes vernalization requirement]</td>
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Lupin domestication genes

The first steps in modern lupin breeding were taken in 1928/29 in Germany with the selection of the first low alkaloid cultivars of L. angustifolius (Cowling et al. 1998). The dominant form of the alkaloid gene (Iuc) results in anthocyanin pigments in cotyledons, flowers and seed coats (Figure 2). It is associated with blue or purple flowers, red hypocotyl and red cotyledons. The recessive forms of the other genes (Moll and Leuc) cause green hypocotyl and green cotyledons.

Most seeds of wild lupins are ‘hard’, i.e. they are impermeable to water (genotype Moll/-). Only a small percentage of seeds swell and germinate each year on contact with water after they fall to the ground. This trait is important for the survival of wild plants, while the recessive mutant moll is useful in agriculture because it allows immediate germination on sowing. In the 1930s (i.e., prior to the development of fully domesticated cultivars), permeable seed coats were discovered in bitter L. angustifolius lines of uncertain origin (Cowling et al. 1998). All cultivated varieties of lupin have soft, water permeable seeds (genotype moll/moll) that germinate as soon as the seed contacts water.

In 1960 Dr J. S. Gladstones discovered mutants with non-shattering pods in fields of bitter cultivated L. angustifolius in Western Australia (Cowling et al. 1998). Two genes (lentus and tardus) were found to be responsible for reduced pod shattering. Both tardus and lentus are recessive mutants. Together, they can eliminate pod shattering in the field (Gladstones 1977). The lentus allele can also be phenotypically identified by red pigment in the cortex of the lower stem and inside pod walls.

The dominant wild-type form of the Leucospermus gene (Leuc) results in anthocyanin pigments in cotyledons, flowers and seed coats (Figure 2). It is associated with blue or purple flowers, red hypocotyl and red cotyledons. The recessive mutation leuc reduces pigment formation, resulting in more or less white flowers, green hypocotyls and green cotyledons. Initially tardus and then both lentus and tardus mutants were crossed into lines with the leucospermus mutants to develop the varieties Uniwhite in 1967 and Uniharvest in 1970 respectively (Cowling et al. 1998). All lupin cultivars in Australia are leuc/leuc with more or less white flowers. Flower colour is used to differentiate the domesticated crop from wild populations which may grow in the same region (Cowling 1999).
Figure 2. Scoring pigmentation on the underside of the cotyledons and hypocotyls. The red pigmentation (left) is caused by the \textit{Leuc} allele; the absence of red pigmentation (right), caused by the \textit{leuc} allele, results in a bright green colour.

\textit{Ku} is a spontaneous dominant mutant allele and was found in a crop of the late-flowering cultivar Borre (Gladstones and Hill 1969). \textit{Ku} is responsible for early flowering time (Cowling 1999) which is important for adaptation to short growing seasons.

Locations of domestication genes

A genetic map of \textit{L. angustifolius} was developed using a mapping population derived from a cross between a domestic line and a natural population originally collected from Morocco which was blue-flowered, late, bitter, hard-seeded, with shattering pods and a non-pigmented cortex at the base of the stem (alleles \textit{Leuc}, \textit{ku}, \textit{luc}, \textit{Moll}, \textit{Ta} and \textit{Le}) (Nelson et al. 2010).

1 3 7 8 10 17

\begin{center}
\begin{tabular}{c}
\textit{Ta} \\
\textit{Leuc} \\
\textit{luc} \\
\textit{Le} \\
\textit{Ku} \\
\textit{Moll}
\end{tabular}
\end{center}

Figure 3. Locations of the major gene trait loci in \textit{L. angustifolius} (2\textit{n}=40 chromosomes).

Conclusion

\textit{L. angustifolius} has undergone domestication in the twentieth century and wild types are readily crossed with the domesticated forms. Several domestication genes separate the wild and domesticated forms. Wild forms may harbour interesting traits such as disease resistance. the progeny of crosses with wild lupins must be reselected for the major domestication genes as well as any other traits of interest. Molecular markers for domestication genes will aid this process.

References


