Lupin breeding in Western Australia: the narrow-leaf lupin (Lupinus angustifolius)

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Recommended Citation
Gladstones, John Sylvester (1975) "Lupin breeding in Western Australia: the narrow-leaf lupin (Lupinus angustifolius)," Journal of the Department of Agriculture, Western Australia, Series 4: Vol. 16 : No. 2 , Article 4.
Available at: https://researchlibrary.agric.wa.gov.au/journal_agriculture4/vol16/iss2/4

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Over the past seven years the narrow-leafed lupin (Lupinus angustifolius) has become a significant crop plant in Western Australia.

The present crop varieties are the result of a long-term breeding programme started in 1954 with the aim of producing a broad-acre crop from a plant well adapted to our light soils but with a number of characteristics which precluded its use for cropping.

To an original sweet narrow-leafed lupin, soft-seededness, non-shattering pods, early flowering and a distinctive appearance to distinguish it from bitter types were progressively added.

The author of this article, Dr. J. S. Gladstones, began lupin breeding at the University of Western Australia in 1954. In 1971 the programme was transferred to the Western Australian Department of Agriculture, when Dr. Gladstones joined the Department as Senior Plant Breeder.

For his work on legume breeding and research, Dr. Gladstones was recently awarded the Farrer Medal for 1975.

The lupin breeding programme was made possible by cereal growers' contributions to the Western Australian Wheat Industry Research Committee and the Soil Fertility Research Fund. Its success is an outstanding example of the dividends which can be returned from industry contributions to agricultural research.
Lupins are new as a commercial crop, but may be very old as a food plant. Types of the Mediterranean white lupin (*Lupinus albus* L.) have been part-developed and used as a subsistence crop for three thousand years or more. Likewise the pearl lupin (*L. mutabilis* Sweet) has been grown for many centuries in the Andean Highlands of South America. In both cases the seeds are boiled and steeped in water for several days to rid them of their bitter, somewhat toxic alkaloids. They are then used directly as a valued protein source in human diets.

Several species of lupin have long been a part of traditional Mediterranean agriculture for green manuring of orchards, vineyards, olive groves, and sometimes cultivated fields. They include the yellow lupin (*L. luteus* L.) and narrow-leafed lupin (*L. angustifolius* L.) as well as *L. albus*.

Of the three species the narrow-leafed lupin is the most widespread in its natural state, occurring on non-alkaline soils all around the Mediterranean where annual rainfall exceeds about 400 mm (Figure 1).

A great diversity of forms exists, ranging from large-seeded types similar to our present bitter cultivated varieties to very small-seeded and often low-growing true wild types. The large-seeded types tend to occur around arable land, and most are probably descendents of recently or anciently cultivated stands. Small-seeded wild types grow both there and in hilly uncultivated country as part of the natural vegetation, or volunteering along roadsides and other disturbed places. Seeds of both types have traditionally been collected and roasted for substitute coffee, or used for food in times of want or for various medicinal purposes.

After about 1850, bitter narrow-leafed lupins, together with bitter yellow lupins, came to be grown to a small extent in northern Europe for green manuring and sheep feed, becoming an important basis of the Saxony Merino wool industry. Lupinosis outbreaks after about 1870 limited their subsequent use for sheep feed, but lupins continued to be widely used for green manuring on the acid, sandy soils of the Baltic coastal plain.

Modern lupin breeding started in Germany in 1928. Food shortages during the 1914-18 war, especially of proteins, had already turned the attention of German scientists to lupins as an adapted plant and possible domestic source of protein. Various industrial methods for debittering lupin seed were devised in the period about 1920. These were technically fairly successful, and it was demonstrated that treated lupin seed could be used satisfactorily in a wide range of human foods.

The processes did not prove economic. They did, however, give rise to the idea that it might be possible to breed forms of lupin free of bitter alkaloids, using natural mutations or "sports". These were suspected to occur, but under natural conditions might be expected to disappear because of their greater attractiveness to insects and grazing animals.

A young German plant breeder, Dr. R. von Sengbusch, undertook the search for an alkaloid-free lupin plant. In 1928 and 1929 he and a team of assistants chemically tested 1 500 000 individual plants for alkaloid content: three of the yellow lupin and two of the narrow-leafed lupin. All five bred true. In the early 1930s von Sengbusch and other German breeders extended the work and found several alkaloid-free, or "sweet" mutants in *L. albus*, the Mediterranean white lupin.

Further searches among field populations revealed natural mu-

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Fig. 1.—Distribution of *Lupinus angustifolius* in its native state. It grows wild around the Mediterranean on coastal sands and on inland sandy to loamy soils of acid to neutral reaction.
tants of the yellow lupin with non-shattering pods, permeable or “soft” seed coats (allowing immediate germination), and white seed colour which allowed ready distinction from the old speckled-seeded bitter varieties. Combination of all these characters into a single line by cross-breeding led to development of the yellow lupin cultivars Weiko II (approved for release in 1943) and Weiko III (1951).

The sweet *L. albus* selections already had non-shattering pods and soft seeds from their origins out of old Mediterranean cultivated types. They were, however, very late maturing, over-tall, and generally ill-adapted to northern European conditions. Several private firms undertook crossbreeding with early-flowering and semi-dwarf selections, resulting most notably in the early, short-growing sweet varieties Ultra (1950), Gela (1950) and Blanca (1957).

Less progress was made with the narrow-leafed lupin *L. angustifolius*.

German and Swedish workers crossed von Sengbusch’s original sweet but hard-seeded selection with bitter but soft-seeded green manuring types to give the sweet, soft-seeded varieties Müncheberger Blaue Süsslupine (1944) and Borre (1947) respectively. Non-shattering pods were sought but not found, and both varieties retained the blue flowers and grey seeds of their bitter ancestors.

Polish and Russian breeders have since bred early-flowering narrow-leafed varieties which have made possible an extension of lupin growing into northern areas with a short summer growing season, but the pods still shatter.

**LUPIN STUDIES IN WESTERN AUSTRALIA**

Investigations on lupins started at the University of W.A. in 1954, and aimed initially to evaluate existing European cultivars. Pure seed of the German cultivar Weiko III (yellow lupin) and the Swedish cultivar Borre (narrow-leafed lupin) was bulked and released to Western Australian farmers in 1959. Sweet *L. albus* varieties available at the time gave generally unsatisfactory results, and none was released.

Experiments and field experience indicated that the sweet cultivars then available were adapted only to areas of the State with an annual rainfall of 500 mm or more, because of their late maturity. Results in lower rainfall areas were erratic and mostly unsatisfactory.

Another conclusion was that, in contrast to most northern European experience, the narrow-leafed lupin is the most widely adapted of the “developed” lupins to Western Australian conditions. Both yellow and Mediterranean white lupins grew well in isolated cases, but generally proved either ill-adapted to local soils or overly susceptible to diseases or insect pests.

The remaining agronomic shortcomings of sweet narrow-leafed lupins (shattering pods, late maturity and similarity in appearance to the already-grown bitter cultivar New Zealand Blue) made them still unsatisfactory for extensive commercial use. A breeding programme was therefore started with the aim of overcoming these disabilities and establishing the narrow-leafed lupin as a true crop plant. This work continued at the University, with financial support from the Western Australian State Wheat Research Committee, from 1960 until 1971, when the programme transferred to the Western Australian Department of Agriculture.

Parallel breeding was undertaken with the locally naturalised sandplain lupin (*L. cosentini* Guss.). This will be described in a later article.

The initial stages of narrow-leafed lupin breeding in Western Australia paralleled earlier German work in seeking natural mutants within existing cultivars (New Zealand Blue and Borre), followed by intercrossing to combine all required characteristics into a final crop type. The individual mutant genes used in breeding and their origins are described below. Figure 2 shows the crossing scheme, or “family tree” of the new varieties developed to date.

**Mutant genes used in breeding:**

- *iucundus* (*iuc*) — reduces the alcaloid content of the plant and seed from about 1.5 per cent to about 0.03 per cent. This is the original “sweetness” gene selected by von Sengbusch in Germany in 1928-29, and is present in all sweet narrow-leafed lupin cultivars.
- *mollis* (*moll*) — makes the seed coat readily permeable to water, allowing immediate seed swelling and germination. The origin of this gene is obscure, but it has long been present in *cv.* New Zealand Blue and some of the older European green manuring varieties.
- *leucospermus* (*leuc*) — prevents production of blue and purple anthocyanin pigments in the plant, resulting in white flowers and seeds and clear green stems, leaves, etc. The flowers take on a slight purplish tinge as they age, and the seeds have small brown markings around the hilum (seed attachment), together with variable faint brownish marbling on other parts of the surface depending on environmental conditions which are not yet understood. The *leucospermus* gene appears quite commonly as a natural mutant of the normal blue flowered type. That used for breeding was selected from a green manure crop of *cv.* New Zealand Blue at Houghton Vineyard, Middle Swan, Western Australia, in September, 1954.
- *tardus* (*ta*) — reduces pod shattering on drying by over-growth and partial fusion of the opposing fibre strands in the pod seams*. Observational evidence suggests that this may be accompanied by slightly enhanced vegetative vigour due to greater stem development, as in *cv.* Uniwhite, but that a slight reduction in pod and seed setting may also occur. The gene was selected in two plants which retained their pods after maturity in a 20 hectare field crop of *cv.* New Zealand Blue at the CSIRO “Glen Lossie” experiment station, Kojonup, Western Australia, in December, 1960. It was subsequently seen in other crops of *cv.* New Zealand Blue in the Boyup Brook district.
- *lentus* (*le*) — reduces pod shattering to a moderate degree by structural changes and weakening of the pod wall, leading to reduced “ex-

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*For a detailed account of the reduced-shattering genes *ta* and *le* see Gladstones, J. S. (1967) — Australian Journal of Experimental Agriculture and Animal Husbandry 7: 360-6.
Wild Mediterranean types. Selection of large seeded types, for green manuring.

Select 1928-9 (sweetness) Origin unknown Origin unknown

Muncheberg Sweet Blue iuc (Germany 1933)

Swedish land types (soft seeds) moll

cv. New Zealand Blue (soft seeds) moll

Selection and crossing below the broken line were done in Western Australia.

Legend

iuc = sweetness
moll = soft-seededness
leuc = white flowers and seeds

Fig. 2—Descent of present Western Australian narrow-leaved lupin cultivars (simplified). Selection and crossing below the broken line were done in Western Australia.

Ku—advances flowering one to three weeks or more by eliminating the narrow-leaved lupin's normal requirement for prolonged exposure to low temperatures (vernalisation) before flowering is triggered. Unlike most mutant genes, Ku is genetically dominant. It was found

Explosive stresses in the pod as it shrinks on drying. The change is accompanied by a purplish brown pigmentation in the inner pod wall, the chemical nature of which has not yet been determined. This change extends through the fibrous tissues of the stem and is faintly present in the inner seed coat layers, so that plants and seeds of le genotype are distinguishable at any time or growth stage. Effects on growth and seed setting appear to be opposite to those of ta, that is, stem growth is if anything slightly reduced but pod and seed setting may be slightly improved. Plants carrying both reduced-shattering genes have more or less fully non-shattering pods, as in the cultivars Uniharvest, Unicrop and Fest. The le gene was found in a single plant in a stand of cv. New Zealand Blue at the University of Western Australia field station, Shenton Park, in December 1960.
in a single early-flowering plant, selected from a crop of cv. Borre on the property of Mr. A. E. Henderson at Kulikup, Western Australia, in September 1961. With normal May planting in Western Australia the difference in flowering time due to Ku ranges from about a month in warm northern areas, such as the Geraldton district, down to 10 days or less in cool southern areas. The difference in any one area is greater with early than with late planting*. Crosses with recently received Russian narrow-leaved lupin varieties indicate that Ku is probably identical with the earliness gene in Severnyj-3 and other Russian early varieties.

- efl—Because of the possible unsuitability of Ku varieties for very early seeding or natural regeneration due to a tendency to flower excessively early under these conditions, alternative earliness genes were sought by artificial mutagenesis**

The efl gene resulted from seed treatment in May 1960 of cv. Borre with 0.24 per cent aqueous ethylene imine. It was selected as the best of 15 mutant early lines examined, and flowers on average 10 to 14 days earlier than Uniharvest, about half way between Uniharvest and Unicrop. The efl genotype has enough vernalisation requirement to


prevent premature flowering in autumn no matter how early it is planted, yet represents a worthwhile advance in earliness compared with Uniharvest over all planting dates. Crossbred lines carrying efl appear to have normal or better vigour and fertility.

Varieties produced

Of the cultivars emerging from the first breeding phase, Uniwhite was released in Western Australia in 1967, Uniharvest in 1971, and Unicrop in 1973. These represent successive steps (see Figure 2) towards an adapted grain variety for Western Australia.

Parallel breeding (Figure 3) has incorporated the earliness gene efl into a fixed crossbred 71A07-B, which in other respects is equivalent to Uniharvest and Unicrop. It is being used as a parent for further crosses in Phase II of the breeding programme (see below).

Cv. Fest, a bitter crossbred obtained early in the programme and one of the parents of Uniharvest, was released in 1973 in response to demand for an improved bitter variety to replace cv. New Zealand Blue for green manuring. It differs from cv. New Zealand Blue only in having non-shattering pods (genes ta and le), which should allow cheaper production of better quality seed. It retains the blue flowers and grey seeds of New Zealand Blue and is therefore readily distinguished from any of the new sweet varieties.

Breeding Phase II—Collaborative programme with the USDA

For some years United States Department of Agriculture workers have carried out an independent narrow-leaved lupin breeding programme at the Coastal Plain Experiment Station, Tifton, Georgia.*

Cultivation of bitter narrow-leaved lupins as a cover and green manure crop on the United States south-east coastal plain began in the 1930s and grew rapidly in the 1940s.

From about 1948 onwards sweet narrow-leaved lupins also came increasingly to be grown, mainly for standing late winter cattle feed.

Problems in the south-east USA included particularly contamination (as elsewhere) of sweet with bitter varieties, because of their similarity of appearance; susceptibility to fungus diseases in the damp and generally mild climate there; and killing by occasional very heavy frosts which even the relatively tolerant L. angustifolius could not withstand.

Introduction of the gene leucospermus for white flowers and seeds into a variety otherwise like Borre gave cv. Blanco (1960). Breeding then concentrated on disease and cold resistance, and the following genes were discovered.

- An—a dominant gene giving resistance to anthracnose (Glomerella cingulata). This gene was found in a wild introduction P.I. 168535 from Portugal. Anthracnose is a serious disease in the American lupin belt but has not so far been significant in Western Australia.
- gl₁—a recessive gene giving resistance to grey leaf spot (Stemphylium botryosum and S. solani). It was found as a natural mutant in a stand of local commercial bitter lupins. A second resistance gene, gl₂, was later located in a wild Portuguese introduction P.I. 168530. Grey leaf spot has been recorded as a serious lupin disease in the USA, northern Europe and New Zealand, and recently has been recognised as causing variable but sometimes substantial yield losses in northern, west coastal and south coastal lupin growing districts of Western Australia.

Sources of resistance to cold down to about —12°C (10°F) was also located among wild Portuguese narrow-leaved lupins and incorporated into the breeding programme. This aspect is not relevant to Western Australian conditions.

The American breeders intercrossed cv. Blanco with lines carrying An and gl₁ to give the sweet, soft-seeded, white-flowered, anthracnose and grey leaf spot resistant variety Rancher (1965)*.

In that year the Australian and American researchers joined forces to combine the advances made by each (Figure 3). Seed of Rancher was sent to Western Australia where it was crossed (1966) with early generation progenitors of Uniharvest. Initial screening of the crossbred progeny for non-shattering pods was carried out in Australia, followed by screening of the survivors for disease resistance in the USA. Alternation of seasons in the two Hemispheres enabled two generations a year to be grown. The crossbred 66A01-2, which combines the characteristics of Uniharvest with resistance to both anthracnose and grey leaf spot, is now being bulked at the Mount Barker Research Station for yield testing and possible release.

66A01-2 has been crossed with Unicrop and with 71A07-B carrying the alternative earliness gene efl (Figure 3). The progenies of these crosses are being selected to combine disease resistance with earliness.

Breeding Phase III—Further yield improvement

So far, narrow-leaved lupin breeding has been concerned with the gross characteristics needed for domestication as a crop plant, together with limited major characteristics (flowering time, resistance to certain diseases and frost) to widen its range of adaptation.

Phase III faces the more complex tasks of increasing the level and reliability of seed yield, finding and exploiting further sources of disease resistance, and widening the species' adaptive range still further. In particular, it is hoped to develop varieties growing and maturing more rapidly than Unicrop for dry parts of the wheatbelt and for late seeding.

Phase III breeding has been in progress since 1970. Varieties arising from it, if any, will probably not become commercially available before the middle 1980s. The varieties and crosses described in this paper will therefore be the main commercial types of narrow-leaved lupin in Western Australia for at least the next decade.