Summary
Two new albus lupin varieties, Luxor\(^1\) and Rosetta\(^1\), have been released by the breeding program. These are the first varieties in Australia with significant pleiochaeta root rot (PRR) resistance. They also have greatly improved yields (Luxor 110% and Rosetta 114%) over the old varieties of Kiev-mutant. The next stage is to combine this increased yield and PRR-resistance with anthracnose resistance. All old albus varieties are rated as very susceptible to anthracnose. There are more than 20 advanced genotypes in trials (2007) with both resistances present. The next generation variety is expected to be released in 2009 or 2010.
CONCLUSIONS

Albus

The level of anthracnose resistance in the Western Australian (WA) bred albus variety Andromeda\textsuperscript{(i)} was insufficient. Along with poor yield, this led to its withdrawal from eastern states by AWB Seeds. The project’s aim was to produce lines with anthracnose resistance as good as the upcoming WALAB2008, or better. This level is lower than that found in cv. Wonga\textsuperscript{(i)} of narrow-leaf lupins but is expected to be sufficient to allow commercial production in the presence of the disease.

Luxor\textsuperscript{(i)} is now the commercial standard for PRR-resistance, while Rosetta\textsuperscript{(i)} is the yield standard (at least in the higher rainfall areas). Kiev-mutant and Ultra remain the standards for flowering time (earliness) but new albus varieties must also have short branches, compact podding zones, high harvest index, and faster maturity (difficult with such large seeds and large, fleshy pods). Phomopsis resistance requires more attention now that progress has been achieved with other diseases. This is being undertaken by a PhD student, Mr Ray Cowley. The NSW Department of Primary Industries (NSW DPI) is also in a position to progress the development of a screening technique to evaluate genetic variation for phytophthora root rot (the next priority disease in albus).

Abiotic and other specific stresses are currently not subject to breeding, except indirectly through yield trials in multiple environments. However, NSW DPI may pursue the following characteristics in more detail: acid soil tolerance (tolerance of aluminium and manganese); salt tolerance; water-use efficiency; drought tolerance; early vigour (cold tolerance in vegetative phase); leaf area index; water-logging tolerance; root penetration ability; and heat tolerance at flowering. Tackling any of these issues would require additional resources. Options are being investigated through the Graham Centre and using NSW DPI royalty funds.

Narrow-leaf

Mandelup\textsuperscript{(i)} is the highest yielding variety, particularly in low-rainfall areas. For high yielding regions, growers require the yield potential of Mandelup combined with the lodging and Phomopsis resistance of Jindalee\textsuperscript{(i)}, as well as the cucumber mosaic virus (CMV) and anthracnose resistance of Wonga.

Recommendations
GRDC should consider funding research to investigate the problem with albus lupins not being used in pig diets.

Outcomes
Economic Benefits

Increased albus lupin yields and improved yield stability (from disease resistance) will increase crop profitability and adoption of lupins as a rotation crop. Mixed cropping enterprises must diversify their cereal rotations with broadleaf crops, particularly legumes. In many areas (e.g. the south-west slopes of New South Wales), albus lupin is the most adapted pulse crop. The new varieties, Luxor\(^P\) and Rosetta\(^P\) are fully suited to all current markets for albus: stockfeed (chickens, horses, cattle, dairy cows, sheep but not pigs) and human consumption.

Current seed stocks of Luxor and Rosetta are free of bitter seed contamination, unlike other commercial varieties) have lower seed manganese levels and large seeds with pure white seed coats. Alkaloid levels are very low (well below the Australian Food Standard) and protein is high. Albus seeds are very suitable for dehulling, and dehulled kernels have a very high protein content.

Luxor and Rosetta were successfully commercialised through Graintrust and granted full Plant Breeders’ Rights (PBR) in May 2007. About 500 tonnes of seed of Luxor will be for sale to growers for the 2008 season, along with about 200 tonnes of Rosetta seed. The new varieties will replace the old varieties (Kiev-mutant and Ultra) very rapidly.

Environmental Benefits

Diversified crop rotations are good for the environment. Lupins reduce the dependency on nitrogenous fertilisers, provide a valuable disease break in cereals, and offer growers alternative herbicide options for weed control.

Each lupin crop fixes atmospheric nitrogen and leaves much of that nitrogen in the soil after harvest in the form of organic matter. The resulting nitrogen is then available to the following crop (typically a cereal or canola) and reduces the dependence on artificial fertiliser. The increased organic matter improves soil health, structure and fertility.

Social Benefits

A higher yielding crop with improved profitability and more reliable production will help to secure the future for farm enterprises. In simple terms, profitable growers can remain in business.

Achievements/Benefits
Albus breeding

The release of Luxor\(^P\) and Rosetta\(^P\) are the key achievements of this project. The breeding program is constantly changing and striving to improve processes to deliver “new varieties, faster”, as well as more efficiently. Albus crossing has been made more reliable and productive. Screenhouse capacity has increased so that more material can be grown in containment to prevent outcrossing. Additional glasshouse space has been secured which is essential for growing lupins out of season. F2 screening has been employed to select PRR-resistant individuals and therefore speed up the breeding process. Anthracnose screening has met with some success at Orange but requires some refinement of the methodology. NSW DPI will validate and implement three new quantitative trait loci (QTL) markers for anthracnose resistance in albus (leading to full marker assisted selection (MAS) for this character) as well as a marker for the pauper low-alkaloid gene in 2008. The markers were produced by colleagues in Perth (Dr Yang). A germplasm exchange agreement (CEA) with the Department of Agriculture and Food, Western Australia - Council of Grain Grower Organisations Ltd (DAFWA-COGGO) albus program has been exchanged. The next new Western Australian albus release, WALAB2008, has been seed increased and is being offered for commercialisation. Approximately 200 kg of WALAB2008 (Andromeda\(^P\)) will be available for 2008 plantings.

NSW DPI has almost completed an analysis of the genetic diversity in the albus breeding germplasm using Expressed Sequence Tag (EST)-based DNA markers from the Australian Research Council (ARC) legume synten project. This will assist in the future design of the crossing program, ensure that the genetic base of the program is sufficiently broad, and allow improved searching for additional disease resistance alleles. The breeding program is now using a Quality Management System (QMS) to improve its overall performance and reliability.
Phytophthora (Sudden Death) can be a significant disease threat to albus crops in wet seasons or waterlogging situations (even if transient). A screening technique is being developed at Tamworth by NSW DPI (Dr Kevin Moore) so that the breeding material can be screened and resistance detected. It remains to be seen whether any resistance will be found in the albus germplasm which can be exploited in new varieties, although the signs from several other crops are positive.

Narrow-leaf evaluation

Narrow leaf lupin (NLL) import and quarantine has been increased in capacity and reliability by moving to a winter-grown, irrigated nursery at Yanco. The few remaining Wagga-bred NLL lines are almost out of the system. NLL seed increase of new released varieties has proceeded well with Coromup\(^{[1]}\) and WALAN2224 (Jenabillup\(^{[1]}\) being offered in the recent call for Expressions of Interest (EOI) to commercialise lupins in the eastern states.

Market-driven

The program has maintained strong links with industry (growers, agronomists, marketers, and end-users), mainly through Pulse Australia and the Eastern Australia Lupin Task Force (EALTF). The breeding aims have been reviewed (by Taverner-Hawthorne and Fellowes) and are well aligned with industry needs. Dr Luckett attended the Corowa Feeds Conference and participated in field days and workshops with growers.

NSW DPI has conducted a free testing service for albus bitter seed, which will continue in 2008-2010. Test results have been provided to growers and their advisers to allow sound sowing decisions to be made. The summary data of this testing for the past five years was submitted to GRDC in August 2007.

Germplasm imports

NSW DPI has continued to import and seed increase albus germplasm from the Perth collection for crossing and screening. Additional sources of resistance to PRR have been identified from this work.

Genomics and mapping populations

The albus lupin component of the ARC legume synteny project work has been to produce and phenotype mapping populations for the key plant traits in the albus breeding program. This is a time consuming but important process. The FI plants must be checked for hybridity using DNA markers known to be polymorphic in the parents. The parent plants must be checked for uniformity and homozygosity. The parental lines must also be phenotyped to ensure that the population will segregate for the target trait(s) as intended. One albus mapping population produced in WA was examined as it was not segregating correctly due to an incorrect parent plant being used. This illustrates the care and skill required in this work to ensure a good outcome.

The mapping populations are phenotyped and then genotyped, and the data used to find markers physically close to the genes of interest. The markers can then be validated and implemented to select the desired character in breeding material. This has several important advantages. It may be significantly cheaper, quicker and easier than the corresponding full phenotypic screening and can be carried out at any time of year and without climatic concerns. It can also be done non-destructively on single seeds or plants.

The albus mapping populations currently under seed increase and phenotyping at Wagga are:

1. Pleiochaeta root rot resistance (source 1).
2. Pleiochaeta root rot resistance (source 2).

This work is continuing as a joint effort between the breeding team and a Charles Sturt University (CSU) PhD student, Ms Cina Zachariah.

Dwarfing and thermoneutrality in albus

Wild albus lupins are long-day plants that have a strong vernalisation requirement. In many commercial varieties,
vernalisation requirement has been removed by the brevis gene and the genotypes are said to be early-flowering. It has been reported in the literature that these early flowering types may exhibit a warm response, i.e. the number of leaf nodes is determined by the number present in the seed plus the number added in response to temperature in the first two weeks after germination. Consequently, a crop sown early in relatively warm conditions would have more leaf nodes before flowering which could result in a tall, bulky crop with poor harvest index. Genotypes which were 'thermoneutral' and did not add many extra leaf nodes under warm germination conditions could be useful in producing more reliable crops with more predictable height and greater yield. One such genotype is the variety Start, from Russia.

In order to investigate whether the thermoneutral phenomenon was real and could be exploited in Australian conditions, crosses were made between Start and local lines. Backcrosses were made and BC1 families were produced so that an undesirable gene for low-alkaloid (exiguus) could be eliminated (Australian varieties use only the pauper gene - any other would cause bitter contamination through outcrossing). The best BC1F7 families are now in their third year of field testing in order to find high yielding, short stature, early flowering types that may have increased utility in the shorter, hotter seasons predicted as a result of climate change.

Many albus lupin genotypes are tall which can lead to crops with large biomass but poor harvest index. The dwarfing character (controlled by two genes) from French breeding lines is being brought into locally adapted varieties. The aim is to reduce plant height and biomass while retaining adequate leaf area index for high grain yield. This material is still being evaluated.

Albus lupin agronomy

The project supervisor is collaborating with NSW DPI staff involved in a GRDC-funded Variety Specific Agronomy Package (VSAP) project which aims to develop best practice management guides for growers on new crop varieties. The lupin breeding group has sown and harvested agronomy trials for the VSAP team for two years. The issues being investigated are time of sowing and plant density. Row spacing will be included in 2008 when suitable sowing machinery is available.

Other research

In 2006, Dr Luckett jointly supervised two B.Sc.Agric. Honours students at CSU. Ms Nicola Wunderlich studied the infection process of Pleiochaeta setosa, a fungal root pathogen of albus lupins that causes significant commercial losses. She achieved First Class Honours. Dr Luckett was joint author on a conference paper resulting from this project. A second conference paper has been submitted, and a jointly-authored journal paper is in preparation.

Ms Melissa Gan investigated the degree of genetic diversity in a collection of Pleiochaeta setosa fungal isolates. She was awarded a 2.1 degree. She used random amplified polymorphic DNA (RAPD), inter simple sequence repeat (ISSR) and enterobacterial repetitive intergenic consensus (ERIC) markers to screen the pathogen collection, and also studied spore morphology. She continued this work for three months using an EH Graham Centre Special Research Grant. The results have been submitted as a conference paper, and a journal paper is in preparation.

Dr Luckett is joint supervisor for two CSU PhD students (2007-2010). Ms Cina Zachariah is continuing the pleiochaeta work in albus lupin and is investigating the genetic control of resistance, identifying resistance genes, and finding markers for breeding. The long-term aim of this work is to clone the resistance genes and to pyramid these in new albus lupin varieties.

Mr Ray Cowley's PhD is on the fungus (Diaporthe toxica) that causes Phomopsis in lupins, and lupinosis in farm animals that graze infected lupin stubble and seeds. Little is known about this disease in albus lupins and whether resistance genes are present in the host. The student will look at developing a robust and reliable screening procedure, assess host genotypic differences, identify sources of resistance in the host germplasm collection, make mapping populations, and find markers. A conference poster has been written to report the initial project findings.

The albus breeding team has collaborated closely with Murdoch University on a three-year ARC-funded legume synteny project.

Dr Luckett collaborated with scientists at Southern Cross University. Studies were conducted on an alkaloid synthesis gene (HMT/HLTase) using its published sequence to design polymerase chain reaction (PCR) primers that amplified both intron and exon portions of the sequence. The aim was to determine whether the gene was present in bitter contaminated albus lupin samples, and what level of polymorphism could be detected between commercial varieties. This was important as it
could help answer the bitter contamination questions facing the albus industry - how did the existing contamination arise, and what was its likely source? This work was successful and has led to a joint publication in Annals of Applied Biology. The results revealed that while the gene was not directly responsible for the pauper low alkaloid phenotype, it was a useful marker that showed contamination most likely arose from cross-pollination with a variety such as Magna P.

The EST-based markers on the lupin map were used to investigate genetic diversity in the Wagga albus breeding germplasm. Dr Rosy Raman was employed for this project. DArT markers will also be used (with funding from NSW DPI royalty funds) by outsourcing to Triticarte in Canberra. A joint publication is in preparation to report on this work.

**Intellectual property summary**

Luxor P and Rosetta P were protected by PBR and commercialised after national advertising and a competitive selection process involving GRDC. End-point royalties will be collected on future crop production.

All future varieties will be similarly protected.

**Additional information**


