# Post maturation and safe storage of pulses

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(Report to the Grains Research and Development Corporation, June 1996)

## Background to the project

Delays in harvesting pulses while the seed dries to reach specified moisture receival standards is known to cause a reduction in yield and deterioration in seed quality prior to storage. Yield losses tend to be most severe in late harvested crops where pods become brittle, which accentuates pre-harvest pod drop, and pod shattering, cracking and splitting of the seed during harvest. Weathering of the mature crop can severely reduce seed viability (Powell, 1985), cause discolouration and bleaching of the seed coat and cotyledons (Maguire, 1973), and increase mould infection levels. The loss in quality impinges directly upon the gross margin obtained by the grower through down-grading of harvested seed, and the pulse industry receives less premium quality seed. This project investigates changes in yield and quality of field peas and lupins over the harvest season to determine the optimum seed moisture content at harvest that maximises yield and quality. The harvesting processes investigated were direct machine harvesting, and windrowing or desiccation followed by machine harvesting.

Windrowing and desiccation are harvesting options that may reduce the problem of uneven ripening within the crop which can delay direct harvesting. The mature standing crop is subject to undesirable weather risks from wind or rain, while seed dries to the required receival moisture content. Cutting the mature crop at an optimum moisture content, windrowing the plants to dry, then threshing the uniformly desiccated pods, can enhance yield and quality. Windrowing can minimise yield losses by reducing pod drop and losses from uncut pods in severely lodged crops, and increase the purity of the seed by curbing the problem of weed contaminants. However, there is an associated risk of severe weather damage if prolonged rain follows cutting. Desiccation involves the pre-harvest application of herbicide to standing crops which hastens crop and weed senescence allowing for more timely harvesting (Warkentin and Sloan, 1996). If harvesting is delayed after desiccation or plants are desiccated too late, yield may be reduced due to over-drying of mature pods or the problems arising from harvesting with reduced plant bulk (Easdown, 1989).

An opportunity exists for growers to maximise their gross margins, particularly where field peas are grown for human consumption, by integrating the optimum harvest process with subsequent safe storage conditions. The industry would also benefit through a greater quantity of premium quality seed for sale on the international and domestic markets. The optimum time for winter grown pulses to reach overseas markets is December/January, but once delivered, may remain in storage for up to 6 months. A large tonnage may also be held by commercial storers for up to a year, or by growers, seeking premium prices, for up to 6 months. Safe storage of pulses depends largely upon the moisture content at the time of harvest, the grain temperature, length of storage, the pulse type, and other factors (Mills, 1992 [citied in Mills and Woods, 1994]). In this project, the interaction of moisture and temperature and their effect on quality was investigated under controlled laboratory conditions to determine the conditions where spoilage occurs, and to define safe storage conditions for prolonged bulk storage.

## Project Aims

To benefit the pulse industry through development of harvesting strategies that improve yield and quality by:

1. developing objective criteria for optimum harvest timing of pulses
2. determining the safe storage limits of moisture and temperature for pulses, in order to set rational receival standards and storage strategies, and to enable earlier harvests, if and when appropriate.

## Executive Summary of Results

The goal of this project has been to enable the pulse growers and commercial handlers to maximise their returns by developing harvesting strategies that maximise yield and quality of the crop and by defining the conditions for its safe storage to maintain that quality.

Timing of the pulse harvest is crucial to maximise yield and quality. After the crop has matured in the field, delays in harvesting until the crop reaches moisture receival limits, especially in seasons of adverse weather conditions, can result in both losses in yield and deterioration in seed quality. This study has investigated the optimum seed moisture content (m.c.) at which to harvest field peas and lupins to maximise yield and quality. In addition, three different harvesting processes, i.e. direct machine harvest, windrowing and desiccation, were evaluated and the harvest losses and changes in seed quality resulting from harvest using each process were quantified for both pulse types.

The optimum time for machine harvesting of field peas (var. Jupiter and Bohatyr) and lupins (var Merrit and Ultra) was found to be when the seed of the mature plant had dried to a moisture content of 15%. Windrowing and desiccation when the seed moisture content ranged from 50 to 30% provided good yield and seed quality, comparable to that of the optimum machine harvest. Delays in harvesting past these levels increased losses in yield through pod drop and shattering, and deterioration of seed quality through reduced germination, increased breakability, and bleaching and discolouration. The data indicates that the current 12% m.c. receival standard for field peas can cause considerable delays in harvesting ripe seed and consequently result in substantial yield and quality losses. A 30% loss in yield, equivalent to an economic loss of $250/ha (Anon, 1996a), was shown to occur when the field pea variety Bohatyr was left to dry "on-head" from 15.5 to 13.8% m.c. The poor colour and higher percentage of split and broken seeds in the late harvested Bohatyr crop would have also resulted in downgrading, compounding the economic loss sustained. The current 13% m.c. receival limit for lupins is more acceptable but higher yields and seed quality would be obtained by harvesting at high moisture contents.

Having harvested the crop at maximum yield and quality, it is necessary to store the crop, often for prolonged periods, without serious loss of quality. Moisture content and grain temperature of pulses at time of harvest play an important part in determining their storability. Storage trials demonstrated that low temperature and relative humidity provide the safest storage conditions for pulses. The suggested moisture content (wet basis) storage limits for field peas and lupins at 20 and 27°C, for either a 3 or 10 month storage period, are given below.

Pulses were stored at 20$^{o}$C without loss of viability or increase in mould levels over a period of 10 months at an equilibrium relative humidity of 70%, which equilibrates to moisture contents (w.b.) of 14.5% for field peas, 14.0% for lupin var. Merrit and 13.5% for lupin var. Kiev mutant. Short-term (3 months) storage at 15% m.c. is unsafe and cooling or drying of the seed in needed.

This study has shown that for maximum yield and quality, pulses should be harvested at somewhat higher moisture contents than is presently the case and subsequently cooled and/or dried (where appropriate) in store to minimise handling of seed post-harvest thereby reducing possible seed damage, and to maintain other quality attributes (particularly germination and colour) for prolonged storage periods.

| Pulse type | 20°C | 20°C | 27°C | 27°C |
|---|---|---|---|---|
| | 3 months | 10 months | 3 months | 10 months |
| **Field Peas** | | | | |
| Jupiter | 14.5 | 13.5 | 13.5 | 12.5 |
| Bohatyr | 14.5 | 13.5 | 13.5 | 12.5 |
| **Lupins** | | | | |
| Merrit | 14.0 | 13.0 | 13.5 | 12.5 |
| Kiev mutant | 13.5 | 12.5 | 13.0 | 12.0 |

## Recommendations

- The moisture content receival limit for field peas should be increased to enable earlier harvesting and delivery of premium quality seed. The data indicates that the current 12% m.c. receival standard for field peas can cause considerable delays in harvesting ripe seed and consequently result in substantial yield and quality losses. Good quality field peas can be safely stored at 13.5% m.c. under aeration, or at 12.5% m.c. in unaerated stores for up to 9 months. Appropriate moisture content receival limits could be established to reflect these safe storage conditions. The current 13% m.c. receival limit for lupins is more acceptable but higher yields and seed quality would be obtained by harvesting at high moisture contents.

- There needs to be major incentive for growers to adopt changes in harvest management such as the use of driers and aeration, including in-bin drying, to reduce the cost of yield and quality losses. An increasing proportion of the pulse crop is being directed to high value food markets, and this reflects relatively favourable gross margins for growers (Anon, 1996b). The strengthening domestic and export demand for high quality pulses, concomitant with the establishment of national quality standards, necessary to support an industry supported marketing program, should provide the incentive to enhance yield and quality through changes in agronomic practice.

- Further studies are required to quantify the benefits obtained from windrowing and desiccation harvest processes. There is consensus that the benefit derived from windrowing or desiccation is largely weather dependant and, given favourable conditions and careful management, higher yields and better quality seed can be obtained using these methods compared to direct machine harvesting.

- Further studies are required to develop optimum harvesting, drying and/or cooling methods that will enable pulses to be harvested at their optimum moisture content.

- Further data is required on the safe storage conditions for the full range of pulses. Growth in the production of pulses is predicted to increase substantially over the next 5 years (Anon, 1995) with an increase in demand for high quality pulses for human consumption. The quantity of premium quality pulses stored on-farm and by commercial handlers will increase to service this demand and therefore fundamental information on the influence of harvest time and storage conditions upon post-harvest quality is essential to ensure marketability of the product is maintained.

## Industry Implications

This study provides information on the optimum seed moisture content at which to harvest field peas and lupins to maximise yield and quality. Three different harvesting processes are evaluated and harvest losses and changes in seed quality resulting from delayed harvest using each process are quantified for both pulse types. The safe conditions for prolonged storage of field peas and lupins are also defined. The information will provide a basis for growers and commercial handlers on which to base harvesting and storage strategies that will enhance yield and quality. The data indicates that delays in harvesting ripe seed to achieve the current 12% moisture content receival standard for field peas can result in substantial yield and quality losses. A 30% loss in yield, equivalent to an economic loss of $250/ha (Anon, 1996a), was shown to occur when the field pea variety Bohatyr was left to dry "on-head" from 15.5 to 13.8% m.c. The poor colour and higher percentage of split and broken seeds in the late harvested Bohatyr crop would have also resulted in downgrading, compounding the economic loss sustained. The current 13% m.c. receival limit for lupins is more acceptable for long-term unaerated storage, but higher yield and seed quality can be obtained by harvesting at moisture contents above this level.

## Detailed Discussion of Results

This report covers in detail the 1995/96 harvest trial carried out at Wagga Wagga and the storage trial on seed from the 1994/95 harvest. The initial harvest trial carried out in Cootamundra (NSW) during the 1993/94 season and the subsequent storability experiment is reported in a CSIRO Technical Paper (publishing date March, 1997). No harvest trial was carried out over the 1994/95 harvest season due to the drought.

## Materials and Methods

### Machine harvest, windrow and desiccant harvest trial

The machine, desiccation and windrowing harvests, were conducted at different times throughout the 1995/96 harvest period at the Agriculture Research Institute at Wagga Wagga. The seed used in the trial was *Lupinus angustifolius* var. Merrit, *Lupinus albus* var. Ultra and *Pisum sativum* var. Jupiter and Bohatyr.

The machine harvest were to occur :

| | |
|---|---|
| early | the earliest time that the header could harvest the crop |
| on-time | 14% seed moisture (w.b.) |
| late | 10 days or more after on-time harvest |

The plots were 12 m long and 1.6 m wide with 4 replicates for each harvest time. The number of pods and loose seeds on the ground were counted before and after harvesting. After harvest, the samples were sieved to remove whole pods, broken pods, stems and dirt. The samples and fractions were then weighed.

The desiccation and windrowing were to occur :-

| | |
|---|---|
| very early | 60% seed moisture (w.b.) |
| early | 25% seed moisture |
| on time | 16% seed moisture |
| control | 12% seed moisture |

The plots were 5 m long and 1.6m wide with the plot being divided one side for desiccation and the other for windrowing. The center 4m was used for the trial with the remainder forming a border. Four replicates were used for each harvest time. At harvest time, the windrow material was hand cut, placed in hessian bags and hung to dry in an gauze sided shed to avoid any changes in quality due to weathering in the field. At each windrow harvest time the moisture content of 5 plants from each replicate were measured.
The plants for desiccation were sprayed with the desiccant Reglone® (diquat, a herbicide that kills photosynthesising parts of the plants) the day after the other half of the plot was windrowed. Seven days after being sprayed, the plants were hand harvested and stored together with the windrowed samples.
On completion of all harvests, the sample were threshed using the header. The field peas were threshed 22 days after the last desiccant harvest, and the lupins, 13 days after the last desiccant harvest. The samples were weighed before threshing and the seed obtained after threshing.

***Commercial desiccation*:** The commercial desiccant trial was conducted at Junee. Initially this was to be a windrow trial but due to the wet season this was considered inappropriate. This trial involved a comparison of desiccated and non-desiccated *Pisum sativum* var. Bohatyr; the seed obtained from the same batch used in the plot experiment at Wagga Wagga.
The commercial trial also looked at the quality of *Pisum sativum* var. Bluey that was machine harvested on time.

### Storage trial

The 1994/95 harvested seed used in the storage trial was *Lupinus angustifolius* var. Merrit, *Lupinus albus* var. Kiev mutant and *Pisum sativum* var. Jupiter and Bohatyr. The seed was initially conditioned at 57, 68 and 80% relative humidity (r.h.), to produce approximately 11, 13 and 15% moisture content (w.b.). Sub-samples of 250g were placed in 500 mL glass jars and exposed to a continuous flow of humidified air of either 57, 68 or 80% r.h. The seed was stored at temperatures of 20, 27 or 35$^{o}$C for time periods of 3, 6 or 10 months. Control samples of both pulse types were also stored at 4$^{o}$C and in a freezer (-20 $^{o}$C) in sealed jars. The samples were removed for quality assessment after 3 months (91 days), 6 months (168 days) and 10 months (308 days).

### Quality testing

***Moisture content*:** The appropriate harvest times were ascertained by removing all the seed from selected plants and moisture content determined by placing the whole seeds in paper bags in an oven at 80$^{O}$C for 2-3 days until there was no further change in weight. The moisture content of seed measured after harvesting and during the storage trial was determined using the ISO standard oven-dried method (Anon, 1985). The two stage vacuum oven method was used for samples over 16% m.c.

***Seed assessment*:** The size of the harvested seeds was measured by sieving 100g samples through 8, 6.35 and 4.76 mm round aperture size screens. The wet weight of the seed was determined per 100 seeds.

***Germination*:** Germination percentage was assessed using the International Seed Testing Association Rules (Anon, 1993). The seeds were germinated between moistened sheets of paper at 20 $^{O}$C in a humidified cabinet without light. Germination of the lupins was assessed at 5 and 10 days and the peas at 5 and 8 days.

***Colour*:** The colour was measured in a standard cell using a Minolta Croma Meter with a CR-310 (50mm diameter) measuring head. The readings were taken using the Commission Internationale de I'Eclairage (CIE) **L*a*b*** system, where from negative to positive **L*** measures dark to light, **a***, green to red, and **b***, blue to yellow. The colour was determined for whole seed and also split field pea seed.

***Breakability*:** To allow for comparison, all sub-samples were pre-conditioned at the same relative humidity of 57-60% for 3 weeks prior to assessment. To determine breakability a 100 g of unbroken sample was processed in a Steinlite Model CK2-M Corn Breakage Tester for 4 minutes. The sample was sieved to remove all broken seeds and the percentage breakability was calculated from the weight of broken seed, compared to the total seed weight.

***Mould*:** Fungal counts were determined by CSIRO Division of Food Science and Technology, Sydney. The samples were assessed by direct and dilution plating onto selective DRBC and DG18 agar media. Plates were incubated at 25$^{O}$C for 5-7 days. Fungi were assessed using a stereo-microscope.

## Results

### Harvesting - processes, yield and quality

***Harvest yield*:** Data on yield and the losses resulting from machine harvesting of field peas and lupins at different moisture contents are given in Table 1. The highest yields for both pulse types were obtained at about 15% m.c. Field peas harvested at 20% m.c. produced the lowest losses due to shattering, but the greater proportion of immature seed that was not threshed from the pod reduced the overall yield. At the lower harvest moisture content, yield losses due to pod drop prior to harvest and shatter due to impact increased substantially. Bohatyr was particularly susceptible to yield losses as the pods dried, with both pod drop and shattering at harvest substantially greater than for Jupiter. For lupins, Merrit was more susceptible to yield losses due to pod drop and shattering, compared to Ultra.

The yields obtained from the windrowed and desiccated harvests are given in Table 2. All windrow and desiccant field peas and the lupin variety Merrit had a moisture content of 10 to 11 % (w.b.) when threshed. Ultra was slightly lower at 7 to 9% moisture content. The yields obtained for field peas cut and windrowed from 50 down to 25% m.c. are comparable to that obtained when seed was direct machine harvested at about 15% m.c. The yields for the lupin variety Merrit when windrowed from 60 down to 20% m.c. exceeded that obtained from direct machine harvesting at 15% m.c. The yields for Ultra windrowed from 70 down to 30% m.c. were comparable to that obtained from the direct machine harvest at 12% m.c. The yields obtained for field peas and lupins where desiccant had been applied to the mature plant, were similar to yields obtained when seed was windrowed at the same moisture contents.

***Germination capacity*:** The germination capacity of field peas obtained using the different harvest processes are given in Figures 1 and 2. The direct machine harvest provided seed of higher germination capacity for both Bohatyr and Jupiter. A substantial reduction in the germination capacity for both varieties resulted when implementation of the windrowing and desiccation harvest techniques were delayed until seed dried to 30% m.c. The lupin variety Merrit maintained a high germinative capacity when cut and windrowed at moisture contents down to 60% (Figure 3). In comparison, the desiccant process affected germination, with less than 60% of the seed germinating following application of desiccant to the crop when seed moisture content was below 20%. The very early windrow and desiccant harvests of Ultra (Figure 4) occurred when the seeds were still immature resulting in the desiccant killing the seeds.

***Breakability*:** The influence of the different harvesting techniques on the susceptibility of field peas Jupiter and Bohatyr to break during handling is shown in Figures 5 and 6 respectively. The data shows that breakage increased the longer harvest was delayed and the application of desiccant and windrowing, as seed progressively dried, accentuated the problem. There was a substantial increase in the breakability of both Jupiter and Bohatyr when the moisture content of machine harvested seed decreased from 15 to 14%. Lupins were less susceptible to breakage during handling, with only 0.1% of Merrit and 0.4% of Ultra seed splitting during testing, and harvest time or harvest technique had negligible influence.

***Seed size*:** The size of lupin seed decreased the later the crop was direct machine harvested. Merrit exhibited a 19% decrease in seeds > 6.35 mm, as the moisture content decreased from 18.5 to 11.3%, and Ultra a 21% decrease in seeds > 8 mm, as the moisture content decreased from 28.7 to 8.6%. There was no significant change in the seed size of field peas over the machine harvest period with > 99% of seeds remaining above 6.35 mm in size. Seed weight (dry basis) of the machine harvest samples showed no significant difference ($p>0.05$) with later machine harvest.

Very early windrowed and desiccated samples contained numerous immature, small seeds in the sample which resulted in poor uniformity of seed size. Ultra that was windrowed/desiccated when the seed moisture content was 82.9%, contained a large number of smaller seeds due to incomplete filling. The seed size for both pulse types remained similar over the remaining windrow and desiccant harvest period. A similar trend was also observed for the seed weight (d.b.). Seed size of the windrow and desiccated samples were generally lower or corresponded to machine harvest seed size at a similar moisture content.

***Mould contamination*****:** The mould infection levels on machine harvested samples were generally low, although the level and diversity of species tended to increase the longer harvest was delayed. Yeasts, *Cladosporium* spp., Hyphomycete spp. and *Penicillium* spp. were found on the majority of samples. The samples had been stored at $4^{o}$C prior to assessment which may have resulted in field fungi such as *Fusarium* and *Dreshlera*, that do not survive well under these conditions, dying off.
The increase in mould levels on seed collected from late harvests in the windrow and desiccated processes were similar to that of machine harvested seed. The species detected on most samples were *Alternaria* spp., *Cladosporium* spp. Hyphomycte spp. and *Penicillium* spp. and yeast.

***Colour*****:** The machine harvested field peas became more bleached in appearance as the harvest progressed, and the change in lightness was quantified using the L*a*b system of measurement. The colour change was most pronounced in Jupiter, with the whole seed and cotyledons fading from a green hue to yellow. The seed coat of very early and early harvested windrowed field peas maintained their green colour, and this was particularly noticeable with Bohatyr. This colouration was not reflected in the Bohatyr seed cotyledons which were the appropriate bright yellow. Desiccation of the field peas reduced the green colouration of the seed coat. The reverse effect was found with the lupins where desiccated early harvested lupins retaining a greenish colouration, and windrowed seed having well developed colour.

***Commercial desiccation trial*****:** The results of germination capacity and breakability for the field pea varieties, Bohatyr and Bluey, used in the commercial scale desiccation trial, are given in Table 3. A portion of the Bohatyr crop was desiccated when the seed moisture content approximated 45% (w.b.), and was harvested 15 days later when the moisture content was 12.8%. The Bluey crop was harvested at a low seed moisture content of 10.3% and the poor germination capacity and high rate of breakage during handling reflect the lateness of the harvest. The Bluey seed was also severely bleached, with a majority of the cotyledons yellow in colour.

## Storage trial

***Germination capacity*****:** The results of the storability assessment for the field peas and lupins are given in Tables 4 and 5 respectively. The decline in seed viability for field peas and lupins was rapid at 35°C and 15% m.c., with all the seed dead within a 3 month period. The viability of field peas stored at 35°C and lower moisture contents (13.1% Jupiter; 13.8% Bohatyr), was maintained above 95% for 3 months. At 20°C, field peas were stored at 14.3% m.c. for 10 months, without substantial loss in viability. The effect of temperature and moisture on the viability of lupin seed was similar to field peas. At low moisture contents (12.3% Merrit; 12% Kiev mutant) seed viability was maintained above 95% for 3 months at 35°C, and for 6 months at 27°C. Higher moisture content seed (13.5% Merrit; 12.7% Kiev mutant) was stored at 20°C for 10 months without substantial loss in viability.

***Breakability*****:** Breakability of the field peas was found not to change with time in storage, but to be related to weather conditions pre-harvest. The repeated wetting and drying of seed during the wet 1995/96 harvest increased breakage in the late machine harvested field peas (Figure 4 and 5). The cultivar Bohatyr had a lower propensity to break in comparison to Jupiter. The initial breakability of the lupins was relatively low compared to the field peas and was found not to increase with storage time.

***Mould contamination*****:** Moulds did not develop on seed stored at $4^{o}$C, although a general low levels of *Cladosporium*, *Penicillium* and yeasts, all of which are well adapted to low temperatures, survived to 10 months. At 20, 27 and 35°C, moulds only developed when the equilibrium relative humidity (e.r.h.) exceeded 0.72 (Table 6). *Eurotium* spp. were the predominant fungi present on both pulse types, with *Aspergillus* and *Penicillium* spp. also present on the field peas. When the e.r.h. ≥ 0.80, infection levels of

*Eurotium* spp. increased rapidly on seed stored at 27 and 35°C. This e.r.h. equilibrates to approximately 16.2 and 15.0% m.c. at 27 and 35°C respectively in field peas, and 15.6 and 15.1% m.c. at 27 and 35°C respectively in lupins. The pre-harvest fungi *Cladosporium* spp. initially present on the seed did not decline on both seed types when the e.r.h. ≥ 0.80. There was a general decline at 10 months in the levels of *Eurotium* spp. detected on both pulse types stored at 35$^{o}$C; the higher temperatures possibly inhibiting growth of the fungi (pers. comm. Hocking, 1996).

***Colour*:** In general, the colour of both seed types was affected by increasing temperature, relative humidity and time in storage. The seed coat became darker and duller as the storage time increased, and the colour change was greater in the field peas, especially variety Jupiter.

## Discussion

### Machine harvest

It is essential that pulse crops are harvested at the correct maturity stage to avoid yield losses through pod drop, shattering and breakage, and to ensure good quality seed. Mature crops often have pods at all stages of maturity and, if a crop is harvested too early, many immature seeds end up in the sample, or the amount of unthreshed pods reduce the yield. The high moisture content of pods at the early machine harvest in this trial resulted in losses due to unthreshed pods passing through the header. The seed from the early harvest also required immediate drying to reduce the risk of mould development. High yields and good seed quality were obtained when seed was machine harvested at seed moisture contents of around 15% m.c. (w.b.). Delays in harvesting, waiting for the seed moisture content to reduce to the 12% m.c. receival standard, resulted in substantial yield losses due to shattering (Table 1) and deterioration in quality, with loss of germination capacity, discolouration due to bleaching, and increased breakability of the seed.

Field peas, especially var. Bohatyr, were particularly prone to yield and quality losses when harvesting was delayed and these losses were accentuated during the rain affected harvest. Armstrong (1995) noted that mature field pea crops left standing for prolonged periods are subject to discolouration and bleaching, shattering , post-maturity weed growth, pea-weevil development and severe lodging. Following wet weather, a lodged crop dries slowly and peas become stained when pods come in contact with moist soil, increasing mould contamination (Heath and Hebblethwaite, 1985). The wet weather experienced over the harvest period resulted in the moisture content of late harvested field peas still exceeding the 12% m.c. receival standard, and it is probable that the economic loss (Table 1) would have been substantially greater had the crop been left standing to dry to this limit.

The lupin variety Ultra was the least susceptible to yield loss due to shattering, but summer weeds became more of a problem with the late harvest of this crop. The large seed size of *Lupinus albus* predisposes seed to damage during harvesting and subsequent storage and harvesting at low moisture contents can results in excessive cracking of the seed coat (May, 1987). This factor may have been reflected by the greater loss in germination with later machine harvest for Ultra (Figure 4) compared to field peas.

Breakability of the field peas was found to significantly ($p<0.05$) increase with delayed harvest (Figure 5 and 6), and the alternate wetting and drying of the pods and seeds due to intermittent rainfall accentuated the problem. The weak stem and rambling habit of Bohatyr predisposed this crop to lodge, increasing yield losses due to shattering during mechanical harvesting and viviparous germination of the seed. Jupiter has a more upright growth habit, enabling more efficient harvesting and reduced seed losses due to shattering.

## Windrow and desiccant harvest

The windrow and desiccant harvest processes produced higher yields when mature plants were cut and windrowed, or desiccant was applied as seed moisture contents decreased from 50 to 30% (w.b.). Good quality seed (i.e. high germinative capacity, low breakage) was obtained when lupins were windrowed early, around 50% m.c. The timing and duration of windrowing and desiccation is critical, and the optimum range of crop moistures to commence these operations is still unclear. Commercial windrowing of lupins by Snowball and Nelson (1984), showed that the optimum moisture content to swath lupins was approximately 50%, which reduced yield losses due to cutting and subsequent machine harvesting and threshing of the seed. Simmons et. al. (1990) suggest windrowing of lupins should commence at 65% and be completed before seed moisture content declines to < 50%.

The application of desiccant to the mature plants did cause fading of the green hue of Jupiter and the white colour of Bohatyr. Uniform seed coat and cotyledon colour in green and white coloured field peas occurs when seed moisture content approximates 30% (Armstrong, 1995). Well developed, uniform seed colour is important in determining the marketability and value of field peas grown for human consumption (McCallum et. al., 1994), and therefore the application of desiccant should be timed to coincide with maximum colour development. At this moisture content, the seed is also likely to have attained maximum size.

The germination capacity of seed from the windrowed and desiccant harvests for both pulse types were lower compared to the direct machine harvested seed (Figures 1 to 4), and the rate of loss increased substantially for late harvests. The mould infection levels on seed from windrowed and desiccated harvests were also higher, and were a probable causal factor of the stunted and weak primary root and epicotyl development obtained in germination tests.

The technique used in this experiment to simulate windrowing of plants, i.e. leaving the seeds in the pods and storing in hessian bags, may have promoted the development of moulds on seed harvested late in the season. This loss in germination and associated mould growth was not observed by Snowball and Nelson (1984), when lupins were windrowed at different seed moisture contents during harvest. The increase in the breakability of late harvested field peas, especially for Jupiter (Figure 5), further supports the suggestion that the storage of windrow and desiccated samples prior to threshing, affected these data.

## Commercial desiccation trial

The germination capacity of field peas collected from the commercial desiccant harvest was lower and seeds were more prone to break in comparison to untreated samples. The germination capacity of Bohatyr (97%) harvested at 14% m.c. was comparable that obtained for Bohatyr machine harvested at the same moisture content at the experimental plots. The commercial desiccant machine harvested samples exhibited a higher germination rate than the seed obtained from hand harvested plants at the experimental plots at a similar harvest time. Bluey, which had lodged to a greater degree than the Bohatyr crop, exhibited low germination capacity, was severely bleached, and was more susceptible to breakage. Lodging of the Bluey crop caused prolonged wetting of the mature pods, resulting in increased mould contamination, and alternate wetting and drying accentuated bleaching and discolouration of the seed. Maguire et. al. (1973) showed that bleaching of the seed coat and cotyledons, when exposed to wet weather during maturation, results in the loss of seed viability and seedling vigour.

### Storability

The conditions considered safe for short-term (3 months) and long-term (10 months) storage under controlled conditions, based on the effects of temperature and relative humidity (and equilibrium m.c.) on changes in seed germination, mould contamination, colour change, and the susceptibility of the seed to break, are given in Table 7. There was negligible change in the quality parameters assessed for seed stored under these controlled conditions for the time specified. The retention of colour in field peas was the quality parameter most sensitive to temperature and discolouration occurred where seed was stored at 27°C at all relative humidities.

Peas and lupins stored at 35$^{o}$C, at all moisture contents, suffered substantial loss in seed viability, change in colour, and increase in mould development. The rate of deterioration in quality was accentuated at 15% m.c. where all seeds for both pulse types were dead within 3 months, and moulds had rapidly developed. Storage fungi have a predominant influence on the loss in seed viability when the relative humidity is high (Ellis et. al., 1982). The most important post-harvest fungi associated with pea and lupin quality deterioration were *Eurotium* spp. The pre-harvest fungi, *Cladosporium* spp., were detected at low levels on seed at 3 and 6 months post-harvest. *Eurotium* spp. and *Aspergillus* Series *restricti* species are tolerant of relatively dry conditions, and are primarily responsible for deterioration in quality of seed during storage. *Eurotium* spp. require an equilibrium relative humidity of 70% to develop (Milton & Jarrett, 1969; Pitt & Hocking, 1985) on seeds. This e.r.h. equilibrates to approximately 13.8 and 13.2% m.c. at 27 and 35°C respectively in field peas, 13.6 and 12.9% m.c. at 27 and 35°C respectively in lupins var. Merrit, and 12.9 and 12.4% m.c. at 27 and 35°C respectively in lupins var. Kiev mutant. At 35°C and 15% m.c., the e.r.h. approximates 80% and conditions are very favourable for the rapid proliferation of moulds. Cooling can be used to reduce the storage temperature, effectively reducing the e.r.h. to a level less favourable for mould growth, thus enabling short-term storage.

The higher moisture content seed stored at 27 $^{o}$C and 80% r.h. also deteriorated, with all the seed dead at 10 months post-harvest and rapid mould growth detected on all samples. Storage conditions at 27°C and 68% r.h. were considered marginal since the e.r.h. for both pulse types exceeded 70% and a low level of mould infection (including *Aspergillus* and *Penicillium* species) developed on seeds in several replicates. The equivalent moisture content (w.b.) of the seed maintained at these conditions were for field peas 13.8% Jupiter, and 14.1% Bohatyr, and lupins 13.6% Merrit, and 13.1% Kiev mutant. The germinative capacity, however, remained above 95% up to 6 months storage. At 27°C and 57% RH, the seed of both pulse types maintained high germinative capacity and mould growth was prevented during a 10 month storage period. Seed stored at 20$^{o}$C and 13% moisture content (w.b.) for Kiev mutant, 13.5% for Merrit, and 14.5% for both field peas, showed no loss in viability or increased mould levels over a 10 month storage period. The equivalent e.r.h. at each of these moisture levels was below 70%, preventing the development of storage fungi.

Retention and uniformity of colour in field peas and lupins was best achieved at lower temperatures and relative humidities. Discolouration during storage of field peas destined for domestic and export human consumption markets is a major quality issue for marketing authorities. Storage of field peas at high temperatures and relative humidities caused a gradual, uniform darkening of the green hue of Jupiter, and the yellow hue of Bohatyr. Storage temperature appeared to be the key factor influencing discolouration of the peas. At 10 months there was a five-fold difference in the degree of colour change between peas stored at 35°C, compared to peas stored at 20°C, and this difference was similar for both varieties stored at 57, 68 and 80% equilibrium relative humidities. The use of cooling would therefore retain the colour of field peas harvested and stored at higher moisture contents.

Breakability of the field peas did not increase with time in storage. The problem of breakage during handling on the farm and by commercial storers appears to be related largely to the field history of the crop. The time of harvest and weather conditions were shown in this study (Figures 5 & 6) to have a pronounced influence on the breakability of seed pre-harvest. Conventional equipment used to handle cereals, i.e. augers and elevators, are not suited to handling pulses, and abrasion and impact during handling are likely to contribute to the overall breakage of seed when outturned.

## Conclusion

The optimum stage of maturity for machine harvesting field peas and lupins was shown to approximate a seed moisture content of 15%. Early harvesting of both pulse types at 15% m.c. enhanced yield and quality, producing seed with high germination capacity, low breakability, uniform seed size, and strong, uniform colour. Harvesting field peas and lupins at this moisture content may enable the crop to precede the wheat and barley harvest. The practice of delaying the harvest of the pulse crop in preference to cereals greatly increases the risk of weather damage to the seed and, as demonstrated during the 1995/96 harvest at Wagga Wagga, result in substantially lower yield and inferior quality seed.

Windrowing and desiccation of the mature crop are options that have been shown to enhance yield and quality. The benefits derived from both these harvesting processes appear to weather dependant and the data from this study indicated that the yield and quality of seed obtained by direct machine harvesting at 15% m.c. was comparable. The additional cost associated with windrowing and desiccation, compared to early machine harvesting, is a factor to be considered when determining the cost benefit of the different harvest processes. The moisture content of the seed, the timing and duration of both harvesting techniques can have a substantial affect upon yield and seed quality, and further evaluation under commercial conditions is required to define these parameters.

Low temperature and relative humidities provided the safest storage conditions for field peas and lupins. The data show that field peas and lupins cannot be stored safely in unaerated storage when harvested at 15% m.c. and therefore the seed would need to be aerated (cooled) or dried to enable safe storage. A low-cost aeration strategy that achieves cooling and drying (where appropriate) would minimise handling of seed post-harvest, reducing possible seed damage, and maintain quality for prolonged storage periods. In recent GRDC sponsored trials, aeration was used ‘on-farm’ to safely store wheat at 14.2% m.c. and, over 5 months period, dry the grain to 13.1% m.c. at a cost of $0.21/tonne. A similar cooling and drying strategy could readily be adopted to ensure the safe storage of early harvested field peas and lupins.

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Table 1. Machine harvest yields and harvest losses of the field peas var. Jupiter and Bohatyr and lupins var. Merrit and Ultra. Estimate of price per ton, $225/ton for the field peas and $230/ton for the lupins, from The Land, 18th June 1996.

| Field pea var. | Harvest date | Moisture content (%, w.b.) | Header yield (ton/ha, d.b.) | Yield from unthreshed pods (ton/ha, d.b.) | Shatter on ground Before harvest (ton/ha, d.b.) | Shatter on ground After harvest (ton/ha, d.b.) | Total potential yield (ton/ha, d.b.) | Harvest loss (%) | Economic loss ($/ha, 12% m.c.) |
|---|---|---|---|---|---|---|---|---|---|
| Jupiter | 16/11/95 | 20.0 | 3.87 | 0.0072 | 0.0015 | 0.197 | 4.1 | 5 | 52 |
| | 23/11/95 | 15.2 | 4.18 | 0.0011 | 0.0000 | 0.322 | 4.5 | 7 | 82 |
| | 8/12/95 | 14.1 | 3.44 | 0.0001 | 0.1914 | 0.557 | 4.2 | 18 | 188 |
| Bohatyr | 16/11/95 | 20.1 | 4.00 | 0.0074 | 0.0000 | 0.200 | 4.2 | 5 | 52 |
| | 23/11/95 | 15.5 | 4.47 | 0.0009 | 0.0014 | 0.321 | 4.8 | 7 | 81 |
| | 8/12/95 | 13.8 | 2.99 | 0.0005 | 0.3361 | 0.971 | 4.3 | 30 | 330 |
| Merrit | 29/11/95 | 18.5 | 3.01 | 0.0450 | 0.0014 | 0.241 | 3.3 | 9 | 74 |
| | 8/12/95 | 15.4 | 2.46 | 0.0061 | 0.0625 | 0.479 | 3.0 | 18 | 141 |
| | 21/12/95 | 11.3 | 2.28 | 0.0025 | 0.2230 | 0.612 | 3.1 | 27 | 216 |
| Ultra | 8/12/95 | 28.7 | 4.29 | 0.0011 | 0.0027 | 0.265 | 4.6 | 6 | 69 |
| | 13/12/95 | 11.8 | 4.60 | 0.0010 | 0.0005 | 0.118 | 4.7 | 3 | 31 |
| | 4/01/96 | 8.6 | 4.03 | 0.0008 | 0.0374 | 0.209 | 4.3 | 6 | 64 |

Table 2. Moisture content of windrow samples at time of harvest and yield obtain from windrow and desiccant samples.

| Legume var. | Harvest date | Moisture content (%, w.b.) | Windrow yield (ton/ha, d.b.) | Harvest date | Desiccant yield (ton/ha, d.b.) |
|---|---|---|---|---|---|
| Jupiter | 31/10/95 | 62.7 | 3.03 | 9/11/95 | 3.34 |
| | 9/11/95 | 49.6 | 3.84 | 15/11/95 | 3.99 |
| | 15/11/95 | 24.9 | 3.81 | 24/11/95 | 4.12 |
| | 24/11/95 | 15.1 | 3.44 | 29/11/95 | 3.95 |
| Bohatyr | 31/10/95 | 65.0 | 3.64 | 9/11/95 | 3.57 |
| | 9/11/95 | 46.6 | 4.17 | 15/11/95 | 4.36 |
| | 15/11/95 | 32.0 | 4.17 | 24/11/95 | 3.99 |
| | 24/11/95 | 14.7 | 4.36 | 29/11/95 | 4.25 |
| Merrit | 10/11/95 | 75.9 | 2.38 | 24/11/95 | 1.97 |
| | 24/11/95 | 57.9 | 3.33 | 29/11/95 | 3.37 |
| | 29/11/95 | 17.8 | 3.40 | 8/12/95 | 3.68 |
| | 8/12/95 | 18.5 | 3.15 | 14/12/95 | 3.44 |
| | 14/12/95 | 10.1 | 2.65 | 21/12/95 | 3.05 |
| Ultra | 10/11/95 | 82.9 | 2.19 | 24/11/95 | 1.26 |
| | 29/11/95 | 67.4 | 4.48 | 8/12/95 | 3.98 |
| | 8/12/95 | 31.9 | 4.39 | 14/12/95 | 4.38 |
| | 14/12/95 | 10.6 | 3.70 | 21/12/95 | 3.99 |

Table 3. Moisture content, germination and breakability of commercially harvested field peas var. Bohatyr and Bluey.

| Field pea var. | Harvest technique | Harvest date | Moisture content (%, w.b.) | Germination (%) | Breakability (%) |
|---|---|---|---|---|---|
| Bohatyr | untreated | 2/12/95 | 14.0 | 97 | 6 |
| | desiccated | 2/12/95 | 12.8 | 91 | 13 |
| Bluey | untreated | 4/12/95 | 10.3 | 34 | 31 |

Table 4. Germination of field peas after storage for 3, 6 and 10 months at different temperatures and relative humidities.

| Field pea var. | 0 month moisture content (%, w.b.) | 0 months germination (%) | Storage temperature ($^{o}C$) | Storage moisture content (%, w.b.) | 3 month germination (%) | 6 month germination (%) | 10 month germination (%) |
|---|---|---|---|---|---|---|---|
| Jupiter | 11.3 | 98 | Freezer | 11.0 | 99 | 100 | 100 |
| | 13.0 | 99 | | 12.9 | 100 | 100 | 99 |
| | 16.1 | 99 | | 15.6 | 100 | 100 | 98 |
| | | | 4 | 11.2 | 96 | 100 | 98 |
| | | | | 12.9 | 100 | 100 | 100 |
| | | | | 15.8 | 100 | 100 | 99 |
| | | | 20 | 11.9 | 99 | 100 | 98 |
| | | | | 14.3 | 100 | 98 | 99 |
| | | | | 17.5 | 97 | 98 | 49 |
| | | | 27 | 11.7 | 97 | 99 | 98 |
| | | | | 13.8 | 93 | 98 | 84 |
| | | | | 16.1 | 91 | 40 | 0 |
| | | | 35 | 11.7 | 92 | 95 | 0 |
| | | | | 13.1 | 97 | 78 | 0 |
| | | | | 14.8 | 0 | 0 | 0 |
| Bohatyr | 10.9 | 95 | Freezer | 10.8 | 96 | 97 | 97 |
| | 13.1 | 96 | | 13.0 | 97 | 97 | 95 |
| | 16.2 | 97 | | 16.0 | 96 | 97 | 95 |
| | | | 4 | 10.9 | 98 | 95 | 95 |
| | | | | 13.0 | 97 | 95 | 95 |
| | | | | 15.9 | 95 | 97 | 97 |
| | | | 20 | 11.9 | 97 | 97 | 96 |
| | | | | 14.3 | 94 | 99 | 94 |
| | | | | 17.3 | 95 | 96 | 74 |
| | | | 27 | 11.7 | 96 | 96 | 92 |
| | | | | 14.1 | 96 | 96 | 93 |
| | | | | 16.3 | 94 | 70 | 0 |
| | | | 35 | 11.9 | 95 | 96 | 0 |
| | | | | 13.8 | 98 | 87 | 0 |
| | | | | 15.2 | 6 | 0 | 0 |

Table 5. Germination of lupins after storage for 3, 6 and 10 months at different temperatures and relative humidities.

| Lupin var. | 0 month moisture content (%, w.b.) | 0 months germination (%) | Storage temperature ($^{o}C$) | Storage moisture content (%, w.b.) | 3 month germination (%) | 6 month germination (%) | 10 month germination (%) |
|---|---|---|---|---|---|---|---|
| Merrit | 11.2 | 98 | Freezer | 11.1 | 99 | 98 | 99 |
| | 12.6 | 100 | | 12.7 | 98 | 99 | 97 |
| | 15.4 | 98 | | 15.3 | 98 | 99 | 97 |
| | | | 4 | 11.1 | 97 | 97 | 96 |
| | | | | 12.6 | 96 | 99 | 98 |
| | | | | 15.3 | 97 | 98 | 97 |
| | | | 20 | 11.3 | 97 | 98 | 95 |
| | | | | 13.5 | 97 | 99 | 97 |
| | | | | 16.8 | 97 | 88 | 4 |
| | | | 27 | 11.7 | 97 | 98 | 97 |
| | | | | 13.6 | 99 | 96 | 79 |
| | | | | 15.6 | 73 | 2 | 0 |
| | | | 35 | 11.1 | 96 | 96 | 97 |
| | | | | 12.3 | 98 | 79 | 10 |
| | | | | 15.3 | 0 | 0 | 0 |
| Kiev mutant | 9.6 | 97 | Freezer | 9.6 | - | - | 91 |
| | 11.5 | 97 | | 11.4 | - | - | 95 |
| | 13.7 | 95 | | 13.9 | - | - | 98 |
| | | | 4 | 9.5 | - | - | 93 |
| | | | | 11.6 | - | - | 96 |
| | | | | 13.8 | - | - | 99 |
| | | | 20 | 10.4 | 94 | 95 | 96 |
| | | | | 12.7 | 95 | 97 | 91 |
| | | | | 15.9 | 95 | 97 | 93 |
| | | | 27 | 10.9 | 97 | 95 | 94 |
| | | | | 13.1 | 97 | 95 | 91 |
| | | | | 15.5 | 94 | 93 | 1 |
| | | | 35 | 10.4 | 96 | 98 | 94 |
| | | | | 12.0 | 96 | 97 | 74 |
| | | | | 14.9 | 1 | 0 | 0 |

Table 6. Mycological assessment of pulses samples before and after storage. Results represent percentage seed infected using direct plating onto DRBC agar, for total yeast and mould counts, and DG18 agar (represented in brackets) for specifying *Eurotium* spp. Where fungi levels, using the dilution plating technique, exceeded 10,000 colony forming units (CFU) per gram of sample the results are given in bold type. Relative humidity obtained from isotherm of pulses at the various temperatures

| Storage temperature ($^{o}$C) | Storage moisture content (%) | Storage relative humidity (%) | 0 months DRBC (DG18) (%) | 3 month DRBC (DG18) (%) | 6 month DRBC (DG18) (%) | 10 month DRBC (DG18) (%) |
|---|---|---|---|---|---|---|
| Field pea var. Jupiter | | | | | | |
| 20 | 11.9 | 56 | 1 (0) | 5 (25) | 0 (0) | 0 (0) |
| | 14.3 | 69 | 1 (0) | 0 (0) | 0 (0) | 0 (4) |
| | 17.5 | 82 | 0 (1) | 0 (15) | 20 (32) | **36 (80)** |
| 27 | 11.7 | 60 | | 0 (0) | 4 (0) | 0 (0) |
| | 13.8 | 71 | | 0 (0) | 0 (0) | 0 (4) |
| | 16.1 | 80 | | **35 (30)** | **36 (52)** | **76 (84)** |
| 35 | 11.7 | 63 | | 0 (0) | 4 (4) | 0 (0) |
| | 13.1 | 70 | | 5 (0) | 0 (0) | 4 (0) |
| | 14.8 | 76 | | **20 (10)** | **64 (84)** | **56 (28)** |
| Field pea var. Bohatyr | | | | | | |
| 20 | 11.9 | 55 | 1 (0) | 5 (0) | 0 (0) | 12 (4) |
| | 14.3 | 69 | 0 (0) | 0 (5) | 0 (0) | 0 (0) |
| | 17.3 | 81 | 0 (0) | 0 (0) | 4 (0) | **80 (96)** |
| 27 | 11.7 | 57 | | 0 (5) | 4 (0) | 0 (0) |
| | 14.1 | 71 | | 0 (0) | 0 (0) | 0 (0) |
| | 16.3 | 80 | | 30 (25) | **64 (60)** | **36 (64)** |
| 35 | 11.9 | 62 | | 0 (0) | 0 (4) | 0 (0) |
| | 13.8 | 72 | | 0 (0) | 0 (0) | 0 (0) |
| | 15.2 | 78 | | **20 (15)** | **28 (40)** | 40 (16) |
| Lupin var. Merrit | | | | | | |
| 20 | 11.3 | 55 | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| | 13.5 | 67 | 1 (0) | 0 (0) | 0 (0) | 0 (0) |
| | 16.8 | 80 | 0 (1) | 10 (0) | **44 (52)** | **84 (64)** |
| 27 | 11.7 | 60 | | 0 (0) | 0 (0) | 0 (0) |
| | 13.6 | 70 | | 0 (0) | 0 (0) | 0 (0) |
| | 15.6 | 78 | | **35 (45)** | **64 (48)** | **28 (20)** |
| 35 | 11.1 | 61 | | 0 (0) | 0 (0) | 0 (0) |
| | 12.3 | 67 | | 0 (0) | 0 (0) | 0 (0) |
| | 15.3 | 79 | | 0 (5) | **32 (64)** | 36 (28) |
| Lupin var. Kiev mutant | | | | | | |
| 20 | 10.4 | 55 | 6 (0) | 15 (5) | 4 (4) | 12 (8) |
| | 12.7 | 67 | 5 (1) | 5 (0) | 4 (8) | 8 (0) |
| | 15.9 | 79 | 1 (1) | 0 (0) | 20 (16) | **60 (68)** |
| 27 | 10.9 | 60 | | 0 (0) | 0 (0) | 20 (0) |
| | 13.1 | 71 | | 0 (0) | 0 (0) | 4 (0) |
| | 15.5 | 80 | | 5 (0) | **52 (80)** | **44 (60)** |
| 35 | 10.4 | 59 | | 0 (0) | 0 (4) | 0 (0) |
| | 12.0 | 68 | | 0 (0) | 0 (0) | 0 (0) |
| | 14.9 | 80 | | **0 (0)** | **32 (40)** | 4 (0) |

Table 7. Seed moisture content (%, w.b.) considered safe for the storage of field peas and lupins at 20 and 27°C under controlled conditions.

| Pulse type | 20°C | 20°C | 27°C | 27°C |
|---|---|---|---|---|
| | 3 months | 10 months | 3 months | 10 months |
| **Field Peas** | | | | |
| Jupiter | 14.5 | 13.5 | 13.5 | 12.5 |
| Bohatyr | 14.5 | 13.5 | 13.5 | 12.5 |
| **Lupins** | | | | |
| Merrit | 14.0 | 13.0 | 13.5 | 12.5 |
| Kiev mutant | 13.5 | 12.5 | 13.0 | 12.0 |

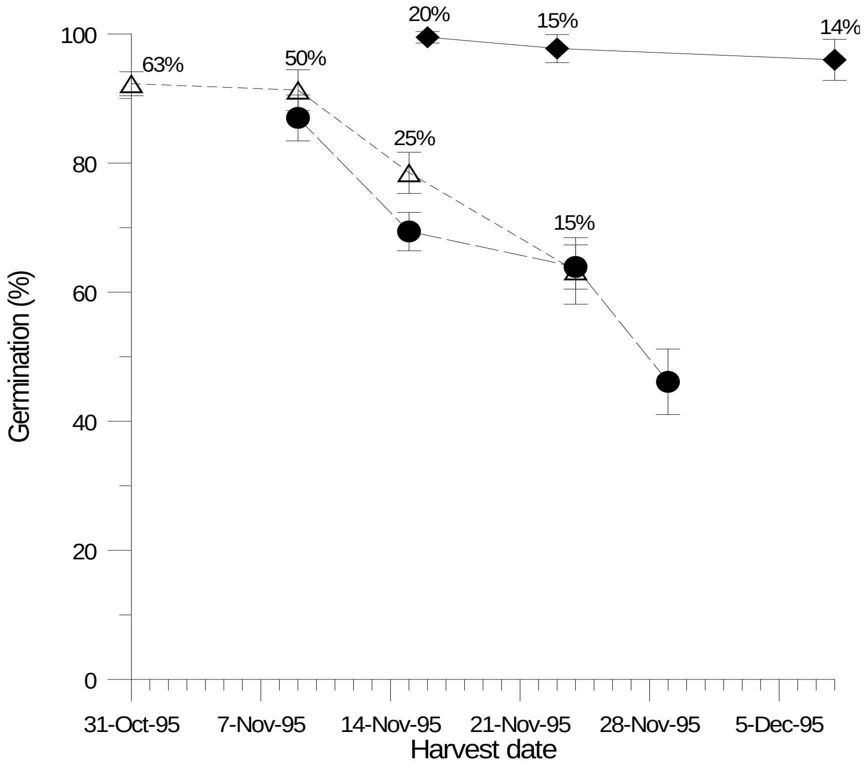


Figure 1. Germination of field pea var. Jupiter: u machine, l desiccant and Δ windrow harvests. Moisture content (%, w.b.) at time of machine and windrow harvest given, bars represent ± standard deviation, n = 4.

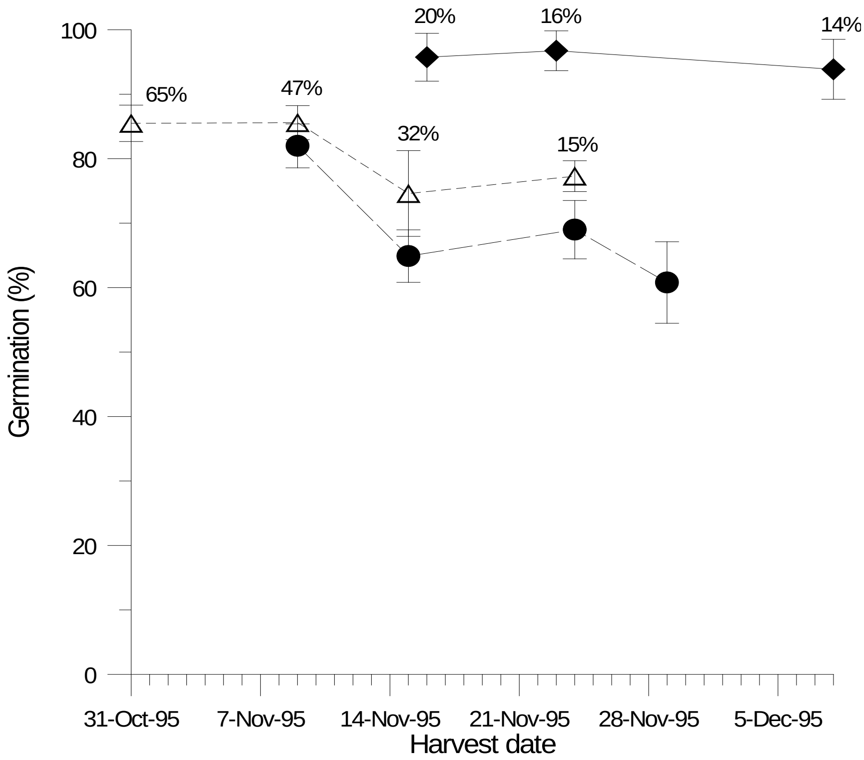


Figure 2. Germination of field pea var. Bohatyr: u machine, l desiccant and Δ windrow harvests. Moisture content (%, w.b.) at time of machine and windrow harvest given, bars represent ± standard deviation, n = 4.

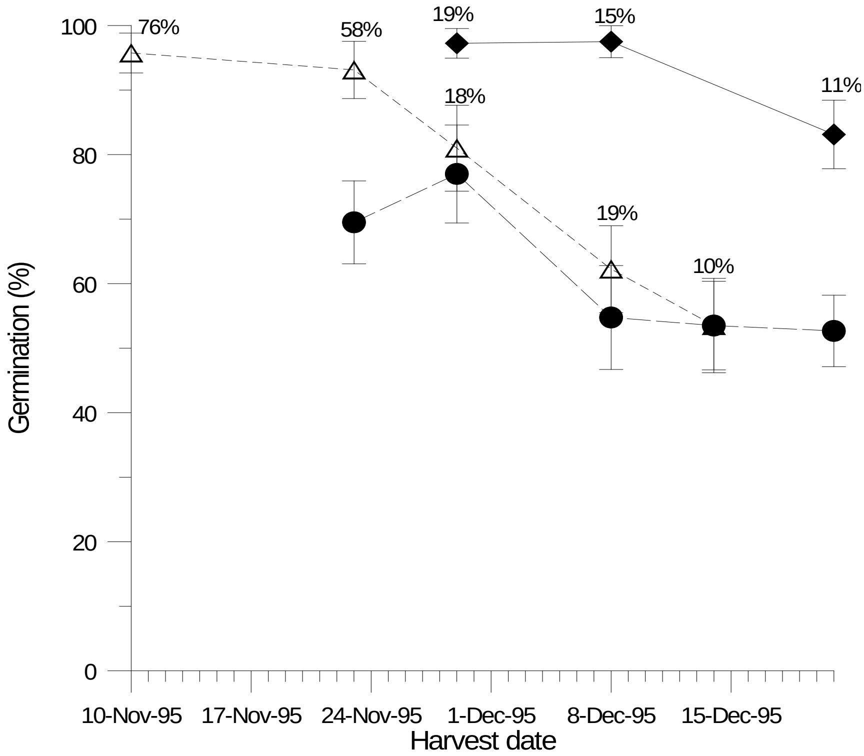


Figure 3. Germination of lupin var. Merrit: u machine, l desiccant and Δ windrow harvests. Moisture content (%, w.b.) at time of machine and windrow harvest given, bars represent ± standard deviation, n = 4.

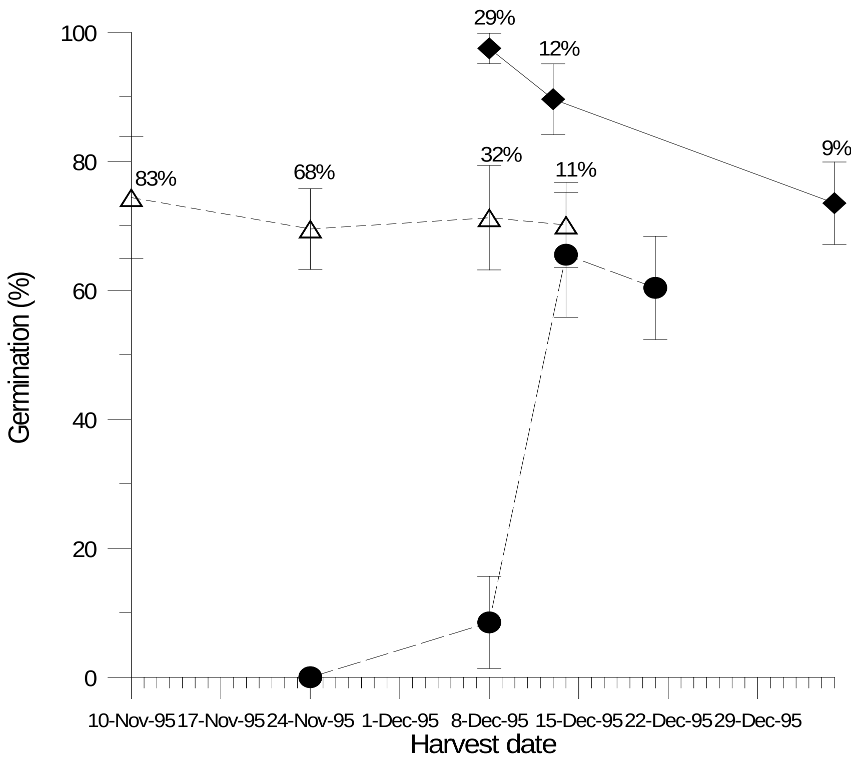


Figure 4. Germination of lupin var. Ultra: u machine, l desiccant and Δ windrow harvests. Moisture content (%, w.b.) at time of machine and windrow harvest given, bars represent ± standard deviation, n = 4.

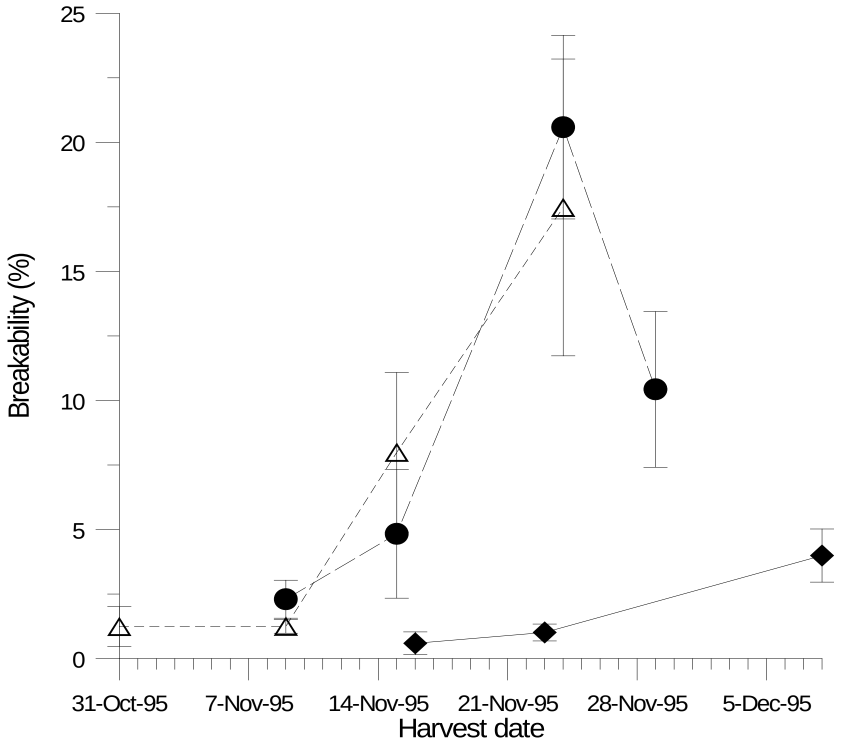


Figure 5. Breakability of field pea var. Jupiter: u machine, l desiccant and Δ windrow harvests. Bars represent ± standard deviation, n = 4.

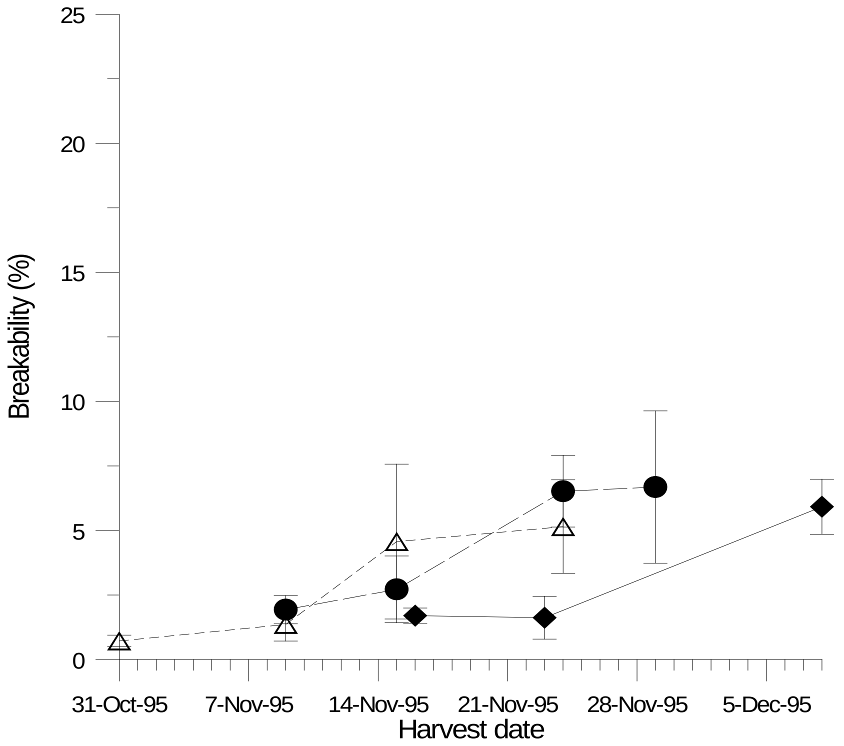


Figure 6. Breakability of field pea var. Bohatyr: u machine, l desiccant and Δ windrow harvests. Bars represent ± standard deviation, n = 4.