PCGIN: Report of Phenotypic Evaluation of Pea Germplasm Micro-Plot Trial over 3 sites in 2006

1.0 Aims and Objectives

The overall aim of this work was to address the current interest of breeders in exotic germplasm and offers an opportunity to observe and assess different and contrasting plant phenotypes to current crop ideotypes as a source of new characters and novel genes.

The overall objective was to establish a common approach to the phenotypic evaluation of germplasm, with particular attention to diverse exotic germplasm selected on the basis of extensive genotype data. Replicated microplot trials of selected germplasm lines would be conducted across three sites (NIAB, PGRO and JIC) over 3 growing seasons. 2006 represents the first year of this multi-site trial.

2.0 Materials and Methods

Micro-plot trial locations: JIC (Norwich), PGRO (Thornhaugh) , NIAB (Cambridge)

Plant material: 20 lines comprising of 18 exotic germplasm lines and two current cultivars as controls. A list of the lines grown is presented in appendix 1.

Experimental design: Complete randomised block design. 60 plots comprising of 3 blocks of 20 lines with 1 replicate per block. Blocks to be run in series or parallel according to land availability. Randomization plans for plot layouts are presented in appendix 2.

Plot size: 1.1m^2 with a minimum of 20cm between plots along the drill. Double wheelings between drill rows to allow easy access for observations.

Plot protection: Walk in netted cages were erected over all plots at all three sites to prevent damage by birds (pheasants, pigeons and crows) and rabbits and hares.

The small plot size required them to be staked as the surrounding ground was kept bare. Observations on lodging can still be made as evidenced by the plots at JIC on 2005.

Crop husbandry: Pre- and post-emergence herbicides were used as required. There is no difference in the sensitivity of the exotic material to herbicides, compared with modern commercial material.

- Seeds were dressed with a proprietary fungicide against damping off and downy mildew.
- Hallmark was used against weevils as required.
- Spraying to try to control downy mildew and aphids was undertaken.

Plot observations: Data was recorded on a list of agreed traits. This included germination, establishment, seedling vigour, flowering and lodging characters. Assessments were made of cold tolerance, weevil damage and signs of any diseases. A copy of the scoring sheet adopted is presented in Appendix 3.

Harvest recording: Detailed records were made on 5 individual plants from the centre and the outside of each plot. Data collected included components of yield for the main stem and branches together with fresh and dry weights.

3.0 Overview of 2006 Weather Conditions and Crop Phenology

Sowing took place in March into a good seed beds (PGRO.23/03, NIAB 29/03 and JIC 28/03. The weather during the period of germination and early establishment were cool and dry offering favourable conditions for peas. There were no particularly cold periods and no cold damage (as evidenced by burning of the leaflet and stipule edges) was recorded on any of the three sites.

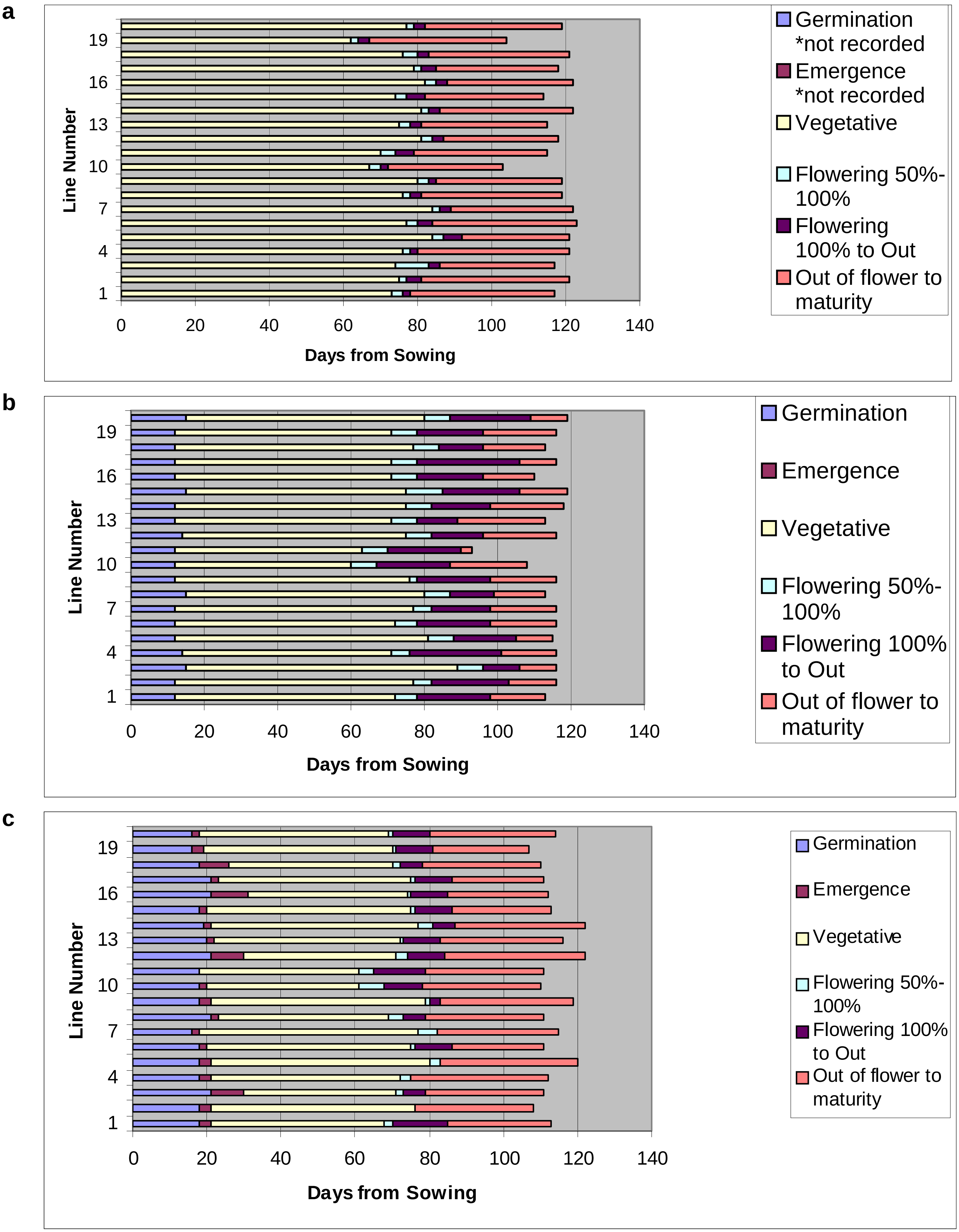
April was slightly warmer than the long term average and a warm spell in the middle of the month saw the sudden emergence of weevils on all sites (section 2.4). May was cool and significantly wetter than average with 173% of the long term rainfall over the month and generally cloudy which proved good conditions for the vegetative grown for all pea lines (Table 1). A few of the early flowering lines (L 3, L 10 and L 11) started flowering during this period. The beginning of June (64 days after sowing) witnessed a sudden change, becoming very hot during the day and warm at night (minimum regional temperature of 16.9 ^{0}C and with little rain (only 39% of the regional long term average). Within a week of this change, signs of heat stress could be observed. The mid-season and later flowering lines flowered during this period, which had the dramatic effect of reducing their flowering periods. These conditions persisted throughout the course of June and continued through July.

Table 1. 2006 monthly weather summaries for East Anglia (Met. Office statistics). *Anomalies = difference from or % from **1961-1990** long term average.

	March		April		May		June		July	
	Actual	Anom*. (^{0}C)	Actual	Anom. (^{0}C)	Actual	Anom. (^{0}C)	Actual	Anom. (^{0}C)	Actual	Anom. (^{0}C)
Max. Temp.	8.8		13.1		17.2		21.1		26.9	
Min. Temp.	1.5		4.4		8.3		10.6		14.3	
Mean Temp.	5.0	*-0.6*	8.8	*0.9*	12.7	*1.5*	16.9	*1.8*	20.5	*4.2*
		(%)		(%)		(%)		(%)		(%)
Rainfall (mm)	37.9	*83*	34.2	*75*	81.3	*173*	16.6	*39*	29.7	*59*

The diverse nature of the germplasm accessions was recorded by noting the times of the different stages of crop development. Crop phenology was recording as 5 distinct phases of crop growth namely i. Germination- the period from sowing to first observed emergence, ii. Emergence period, ii. Vegetative phase- end of emergence to 50% flowering, iv. Flowering 50%-100% and v. Flowering from 100% until out of flower, vi out of flower to maturity. Crop phenology for all the lines on each of the three sites is displayed in Fig.1.

Fig. 1. Crop phenology for micro-plots grown at PGRO (a), NIAB (b) and JIC (c).



3.1 Emergence and Establishment

Emergence was first observed at NIAB over a period of 5 days (12-15 days from sowing) while at JIC emergence was recorded over a 5 day period (18-21 days from sowing). Time to 50% emergence recorded at JIC was generally between 2-3 days from the date of first seedling observed with the large seeded L11 (JI 813) all coming through on the same day. Four lines showed a more staggered emergence of between 8-10 days, L 3 (JI181), L 12 (JI1089), L 16 (JI2201) and L 18 (JI2605). Experience in the past has established that one cause for this may be due to thicker seed coats in certain germplasm, which leads to variable times of imbibition. This is known to be the case with L 16.

3.2 Vigour

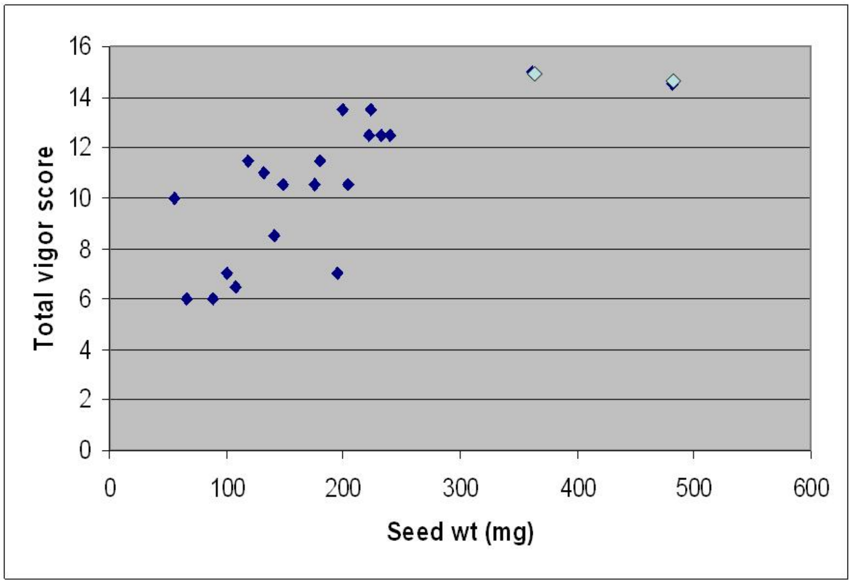
The assessment of vigour is done shortly after emergence and is an indication of how quickly the seedlings start to grow. There was broad agreement between the majority of scores across all three sites especially for the weaker and more vigorous scores (Table 2). The lines exhibiting weaker vigour were L3 (JI 181), L4 (JI 45) L12 (JI 1089), L 16 (JI 2201) and L 17 (JI 2551). It is interesting to note that four of these lines (L3, L12, L16 and L18 exhibited longer emergence periods (3.1). The highest vigour was recorded in L 6 (JI 216), L 9 (JI 284), L10 (JI 399), L 11 (JI 813) and L13 (JI 1194). This scoring system appears robust over the three sites in this study and highly transferable.

Table 2. Average values of vigour across three replicates at each site.1=very poor, 5= excellent.

Line	**PGRO**	**NIAB**	**JIC**	**Total over sites**	**Seed wt (mg)**
(1) JI 15	**4**	**3.5**	**4**	**11.5**	**204**
(2) JI 45	**2**	**3**	**5**	**10**	**56**
(3) JI 181	**1.5**	**2.5**	**2**	**6**	**89**
(4) JI 188	**2.5**	**3.5**	**1**	**7**	**195**
(5) JI 201	**3.5**	**5**	**3**	**11.5**	**180**
(6) JI 216	**5**	**5**	**5**	**15**	**361**
(7) JI 228	**4**	**3.5**	**3**	**10.5**	**175**
(8) JI 281	**2**	**3.5**	**3**	**8.5**	**141**
(9) JI 284	**4.5**	**4**	**4**	**12.5**	**222**
(10) JI 399	**4**	**4.5**	**5**	**13.5**	**200**
(11) JI 813	**5**	**4.5**	**5**	**14.5**	**482**
(12) JI 1089	**2**	**2.5**	**2**	**6.5**	**108**
(13) JI 1194	**4.5**	**4**	**4**	**12.5**	**240**
(14) JI 1428	**3.5**	**4**	**4**	**11.5**	**119**
(15) JI 2105	**3.5**	**3.5**	**4**	**11**	**132**
(16) JI 2201	**1**	**4**	**2**	**7**	**101**
(17) JI 2551	**1.5**	**2.5**	**2**	**6**	**66**
(18) JI 2605	**3.5**	**4**	**3**	**10.5**	**149**
(19) Bilbo	**4**	**4.5**	**5**	**13.5**	**223**
(20) Cooper	**4.5**	**3**	**5**	**12.5**	**233**

As an assessment of early growth there is a question mark as to how closely this index might be linked to the embryonic axis of the seed. While embryonic axis is not wholly correlated with the size of the seed the relationship holds fairly well. Fig. 2 shows the relationship between total vigour score versus the seed weight of the line and reveals a significant association between these two traits. The two marrowfat lines L11 (JI 813) and L6 (JI 216) had the highest vigour values. A correlation restricted to all non-marrowfat lines gave an $r^2 = 0.940$. It is clear from the graph however that, while there is a strong correlation, there are instances where individual lines were poorer than their seed size would indicate (L4, JI 188) or where the converse was true (L2, JI 45).

Fig. 2. Total vigour score across three sites versus seed weight of line. Symbols: light blue= Marrowfat, dark blue= non-marrowfat.



3.3 Weevil Damage (*Sitona lineatus* L.)

Adult weevils emerge from the soil during the first spell of warm weather which coincides with the early juvenile phase of the crop. The weevils feed on the leaflet and stipule margins cutting characteristic notches. Weevils were reported on all three sites with predation being particularly heavy and prolonged on the NIAB plots where three applications of pesticide were applied.

Data was recorded on a 1 to 5 scale (light notching to 5= heavy notching on majority of leaflets) and was assessed on 2 of the three sites (NIAB and JIC).

Table 3. Weevil damage to leaflet margins. Replicate scores for each site are followed by totals and rank orders from highest and lowest scores in brackets.

Line	NIAB	JIC	Total over sites
(1) JI 15	1,5,2 = 8	1,3,1 = 5 (3)	13
(2) JI 45	4,2,2 = 8	1,1,1 = 3 (1)	11
(3) JI 181	5,2,5 = 12 (10)	1,2,3 = 6	18
(4) JI 188	3,2,3 = 8	2,3,1 = 6	14
(5) JI 201	3,3,5 = 11 (9)	3,1,3 = 7 (8)	18
(6) JI 216	2,5,1 = 8	2,1,1 = 4 (2)	12
(7) JI 228	2,,3,4 = 9	2,3,4 = 9 (10)	18
(8) JI 281	3,1,4 = 8	1,1,1 = 3 (1)	11
(9) JI 284	1,3,2 = 6 (3)	2,1,3 = 6	12
(10) JI 399	1,1,1 = 3 (1)	3,1,3 = 7 (8)	10
(11) JI 813	1,1,2 = 4 (2)	1,1,3 = 5 (3)	9
(12) JI 1089	4,5,1 = 10 (8)	1,2,3 = 6	16
(13) JI 1194	4,1,2 = 7	1,1,2 = 4 (2)	11
(14) JI 1428	2,1,5 = 8	2,1,2= 5 (3)	13
(15) JI 2105	4,2,4 = 10	3,1,2 = 6	16
(16) JI 2201	3,3,2 = 8	1,2,2 = 5 (3)	13
(17) JI 2551	2,4,5 = 11 (9)	2,2,3 = 7 (8)	18
(18) JI 2605	4,2,2 = 8	3,2,3 = 8 (9)	16
(19) Bilbo	2,1,3 = 6	1,1,2 = 4 (2)	10
(20) Cooper	2,5,2 = 9	1,2,1 = 4 (2)	13

Scores for accessions showed variation among lines within each site but there was also a high degree of variation among the three replicates (Table 3). On the NIAB site lines scored across the whole 1-5 scale. The lines with the least damage were lines L10 (JI 399) and L11 (JI 813) with low replicate scores across all three reps. On the JIC site lines scored across 1–4 with the lines showing the least damage being L2 (JI 45), L 8 (JI 281) followed by L 6 (JI 216), L13 (JI 1194), L19 Bilbo and L20 Cooper. There was little consistency in the scores or ranks for lines across the two sites. L 19 Bilbo and L 20 Cooper were not as high ranking in the NIAB trial.

Summary: *Level of infestation and degree of damage is site dependent. Evaluation of relative resistance to damage as evidenced across these two sites suggests that replicates of a single line within a site show significant variation and performance ranking at one site does not appear to correlate well across sites.*

Comparing over both sites, L 11 (JI 813) was the most consistent with the lowest score at NIAB and ranked third at JIC.

3.4 Flowering Time

The ranges of days to 50% flowering across the 20 lines for each of the sites was recorded as 19 days (65-84 days) at PGRO, 23 days (62-85 days) at NIAB and 19 days (61-80 days) at JIC (Table 4). The ranking clearly shows that L10 (JI 399) and L 11 (JI 813) were the earliest to reach 50% flowering at each of the three sites and L5 (JI 201) as the latest at PGRO and JIC and just a day behind the latest at NIAB (L3 (JI 181).

Table 4. Days from sowing to 50% flowering and ranking for all three sites together with the difference in days to 50% flowering for lines at NIAB and JIC compared to PGRO.

	PGRO		**NIAB**			**JIC**			Range of Difference between sites (days)
Line No	50%	Rank	50%	Rank	Diff to PGRO	50%	Rank	Diff to PGRO	
(1) JI 15	**75**	**4**	**74**	**3**	*-1*	**69**	**2**	*-6*	**6**
(2) JI 45	**78**	**7**	**80**	**5**	*+2*	**79**	**8**	*+1*	**2**
(3) JI 181	**77**	**6**	**85**	**7**	*+8*	**71**	**3**	*-6*	**14**
(4) JI 188	**76**	**5**	**74**	**3**	*-2*	**73**	**4**	*-3*	**3**
(5) JI 201	**84**	**11**	**84**	**6**	*0*	**80**	**9**	*-4*	**4**
(6) JI 216	**77**	**6**	**74**	**3**	*-3*	**76**	**7**	*-1*	**3**
(7) JI 228	**84**	**11**	**80**	**5**	*-4*	**79**	**8**	*-5*	**5**
(8) JI 281	**76**	**5**	**80**	**5**	*+4*	**69**	**2**	*-5*	**11**
(9) JI 284	**80**	**9**	**78**	**4**	*-2*	**74**	**5**	*-6*	**6**
(10) JI 399	**65**	**1**	**62**	**1**	*-3*	**61**	**1**	*-4*	**4**
(11) JI 813	**71**	**2**	**65**	**2**	*-6*	**61**	**1**	*-9*	**10**
(12) JI 1089	**78**	**7**	**78**	**4**	*0*	**71**	**3**	*-7*	**7**
(13) JI 1194	**75**	**4**	**74**	**3**	*-1*	**79**	**8**	*+4*	**5**
(14) JI 1428	**80**	**9**	**78**	**4**	*-2*	**79**	**8**	*-1*	**2**
(15) JI 2105	**74**	**3**	**74**	**3**	*0*	**75**	**6**	*+1*	**1**
(16) JI 2201	**80**	**9**	**74**	**3**	*-6*	**75**	**6**	*-5*	**6**
(17) JI 2551	**79**	**8**	**74**	**3**	*-5*	**75**	**6**	*-4*	**5**
(18) JI 2605	**76**	**5**	**80**	**5**	*+4*	**71**	**3**	*-5*	**9**
(19) Bilbo	**81**	**10**	**74**	**3**	*-7*	**79**	**8**	*-3*	**7**
(20) Cooper	**77**	**6**	**80**	**5**	*+3*	**74**	**5**	*-3*	**6**

The sowing date on each site covered a range of 6 days (PGRO 23/03, NIAB +6 and JIC +5). This difference coupled with the differences in soil, rainfall and temperature at the three localities impacted on the crop phenology (Figure 1) and on flowering time which is to be expected. The ranking of lines helps remove these differences. It is interesting however to note that the range of days for each line to reach 50% flowering expressed as a difference across all sites showed wide differences between lines with L 15 (JI 2105) showing a range of just 1 day and L 3 (JI 181) a range of 14 days.

3.5 Canopy Architecture

Canopy architecture is of key component of crop performance and is dependent on a number of individual components which change during the ontogeny of the crop. Initially, key features include uniform germination and the formation of attachments between neighbouring plants. This is essential to help overcome the inherent weakness of the base of the stem. The ability of the canopy to develop height while accumulating biomass is important for the flowering and pod setting phases of development. There were striking contrasts among the exotic lines in terms of leaflet size, internode length and branching. A key objective was to record how these contrasting exotic forms performed with respect to canopy lodging. Resistance to lodging or traits that could be further studies and dissected genetically were important goals for the study. The recording of lodging was therefore broken down into a series of categories relating to crop attitude in addition to crop height at flowering and maturity, which form the basis of the next tow sections.

3.6 Lodging and Crop Attitude

Improving lodging resistance remains a key priority for improving the pea crop. Lodging is a complex character and was broken down into a series of separate criteria to capture the range of behaviour of lines. Basal sag is the description of a crop where the weight of the canopy cannot be fully supported by the weaker basal section, which can sink down to varying degrees. Leaning refers to the tendency of the whole crop to lean over in one direction due to a number of factors. Creeping habit refers to the ability of a crop that may lean or has lodged early to proceed to grow upwards again, thus maintaining the flowers and pods off the ground. Examples of all these conditions are presented in Fig. 3.

Fig. 3. Examples of different types of lodging.

Basal Sag

Leaning

Leaning and creeping

It should be noted that both current commercial lines L19 Bilbo and L20 Cooper are semi-leafless types which carry the *af* allele. The additional tendril mass resulting from this allele results in a significant improvement in standing ability with which to contrast with the exotics. As expected, the overall scores for lodging at maturity of these two cultivars exhibited the most consistent resistance to lodging with the highest numbers of N scores (Table 5). The NIAB data show at least one replicate of L3 (JI 181), L11 (JI 813) and L 16 (JI 2201) as not lodged. L16 (JI 2201) was also scored as not lodged at JIC.

Table 5. Overall lodging score for each replicate at maturity (Yes/No). (A dash indicates where an observation was not recorded).

Line	**PGRO**	**NIAB**	**JIC**
(1) JI 15	Y,Y,Y	Y,Y,Y	Y,Y,Y
(2) JI 45	Y,Y,Y	Y,Y,Y	Y,Y,Y
(3) JI 181	Y,Y,Y	**N**,Y,Y	Y,Y,Y
(4) JI 188	Y,Y,Y	Y,Y,Y	Y,Y,Y
(5) JI 201	Y,Y,Y	Y,Y,Y	Y,Y,Y
(6) JI 216	Y,Y,Y	Y,Y,Y	Y,Y,Y
(7) JI 228	Y,Y,Y	Y,Y,Y	Y,Y,Y
(8) JI 281	Y,Y,Y	Y,Y,Y	Y,Y,Y
(9) JI 284	Y,Y,Y	Y,Y,Y	Y,Y,Y
(10) JI 399	Y,Y,Y	Y,Y,Y	Y,Y,Y
(11) JI 813	Y,Y,Y	Y,**N,N**	Y,Y,Y
(12) JI 1089	Y,Y,Y	Y,Y,Y	Y,Y,Y
(13) JI 1194	Y,Y,Y	Y,Y,Y	-, Y,Y
(14) JI 1428	Y,Y,Y	Y,Y,Y	Y,Y,Y
(15) JI 2105	Y,Y,Y	Y,Y,Y	Y,Y,Y
(16) JI 2201	Y,Y,Y	Y,Y,**N**	-, **N**, -
(17) JI 2551	Y,Y,Y	Y,Y,Y	Y,Y,Y
(18) JI 2605	Y,Y,Y	Y,Y,Y	Y, -, -
(19) Bilbo	Y,Y,Y	**N,N,**Y	**N**,Y, -
(20) Cooper	**N,N,N**	**N,N,**Y	-,Y

Table 6. Scores for basal sag (B), leaning (L) and creeping habit (C) in triplicate microplots across three sites. All scales on 1 – 5, where 1 = poor, 5 = good, i.e. 5 = upright plants with little expression of any of the lodging components. A dash indicates where that lodging component was scored independently as 'No', i.e. plants exceeded a score of 5 for that lodging component. (Note there were two, rather than three, replicates of Cooper at JIC).

Line	**PGRO**			**NIAB**			**JIC**		
	B	L	C	B	L	C	B	L	C
(1) JI 15	- - -	- - 4	355	- 4 -	- 3 -	354	- - -	233	2 -3
(2) JI 45	33 -	554	- - -	- - -	- - -	534	- - -	212	- - -
(3) JI 181	- - -	343	334	- - -	- - -	- 55	- - -	143	- - -
(4) JI 188	- - -	433	434	5 -5	- - 5	223	- - -	233	- - -
(5) JI 201	- - -	544	3 - -	- - -	- - 4	45 -	3 - -	132	- - 3
(6) JI 216	- - -	334	- - -	- 5 -	- - 3	434	- - -	122	- - -
(7) JI 228	- - -	433	- - -	- - -	4 - -	433	3 - -	122	3 - -
(8) JI 281	- - -	555	- - -	45 -	- - -	534	3 - -	111	- - -
(9) JI 284	- - -	555	- - -	- - 5	- - 5	324	- - -	122	- - -
(10) JI 399	- - -	333	- - -	- - -	443	445	- - -	111	- - -
(11) JI 813	- - -	334	- - -	- - -	- - -	4 - -	- - -	132	- - -
(12) JI 1089	- - -	555	5 - -	- - -	4 - -	442	- - -	314	4 - -
(13) JI 1194	- - -	444	- - -	- - -	32 -	- 53	- - -	121	- - -
(14) JI 1428	- - -	332	444	4 - -	- 4-	543	3 - -	312	4 - -
(15) JI 2105	554	333	- - -	- - -	- - -	555	- - -	122	- - -
(16) JI 2201	- - -	333	- - -	- - -	3 - -	43 -	- - -	424	- - -
(17) JI 2551	- - -	555	555	5 - -	- - -	555	- - -	222	- - -
(18) JI 2605	- - -	555	5 -5	554	355	- 44	3 - -	244	- - -

(19) Bilbo	- - -	**121**	- - -	- - -	- - -	- - **5**	- - -	- **3** -	- - -
(20) Cooper	- - -	**1** - -	- - -	- - -	- - **3**	- - **5**	- -	- **2**	- -

Basal sag was noted in occasional lines at the three sites (Table 6). The lines at PGRO were two replicate plots of L2 (JI 45) with moderate scores and L 15 (JI 2105) with slight basal sag. At NIAB basal sag was recorded in eight lines but all scores were again slight (4/5 indicating slight sag). L15 (JI 2105) and L18 (JI 2605) showed slight basal sag in three replicates at PGRO and NIAB, respectively. At JIC moderate scores were recorded in single replicates of five lines.

The two lines recorded with basal sag at PGRO did not exhibit sag in any replicates at NIAB or JIC. The character appears to be highly environmentally influenced. Lines exhibiting the character may exhibit it but only under some conditions.

Leaning was observed in all replicates of 18 lines at PGRO and in single replicates of the remaining two lines, L1 (JI 15) and L20 (Cooper). The severity of leaning in L19 (Bilbo) and L20 (Cooper) was more severe. The incidence and severity of leaning at NIAB was overall less pronounced with only L10 (JI 399) and L 18 (JI 2605) showing slight or moderate lean in all three replicates. Two replicate plots of L13 (JI 1194) were scored as significantly leaning (3, 2). The scores for leaning at JIC were generally much lower, i.e. the degree of lean was more severe. L8 (JI 281) and L10 (JI 399) were scored as severely leaning (111) in all three replicates and L13 (JI 1194) recorded similarly (121). At JIC, L19 (Bilbo) and L20 (Cooper) were the only lines where no leaning was recorded for one or more replicates. L16 (JI 2201) and L18 (JI 2605) both recorded two replicates with little leaning (4 score), although the third replicate was scored as 2 in each case.

Creeping habit represents the ability of a line to recover once it has leant over or lodged to any degree. Creeping was most widely observed amongst lines at NIAB where at least one replicate of every line registered a score. Creeping was recorded in eight lines at PGRO and five lines at JIC. Again, the ability of lines to creep following leaning was not consistent across sites with the exception of L1 (JI 15) where all replicate plots at PGRO and NIAB and two at JIC were scored as having moderate to slight creep. L14 (JI 1428) showed creep for 3 replicates at two sites (Table 6).

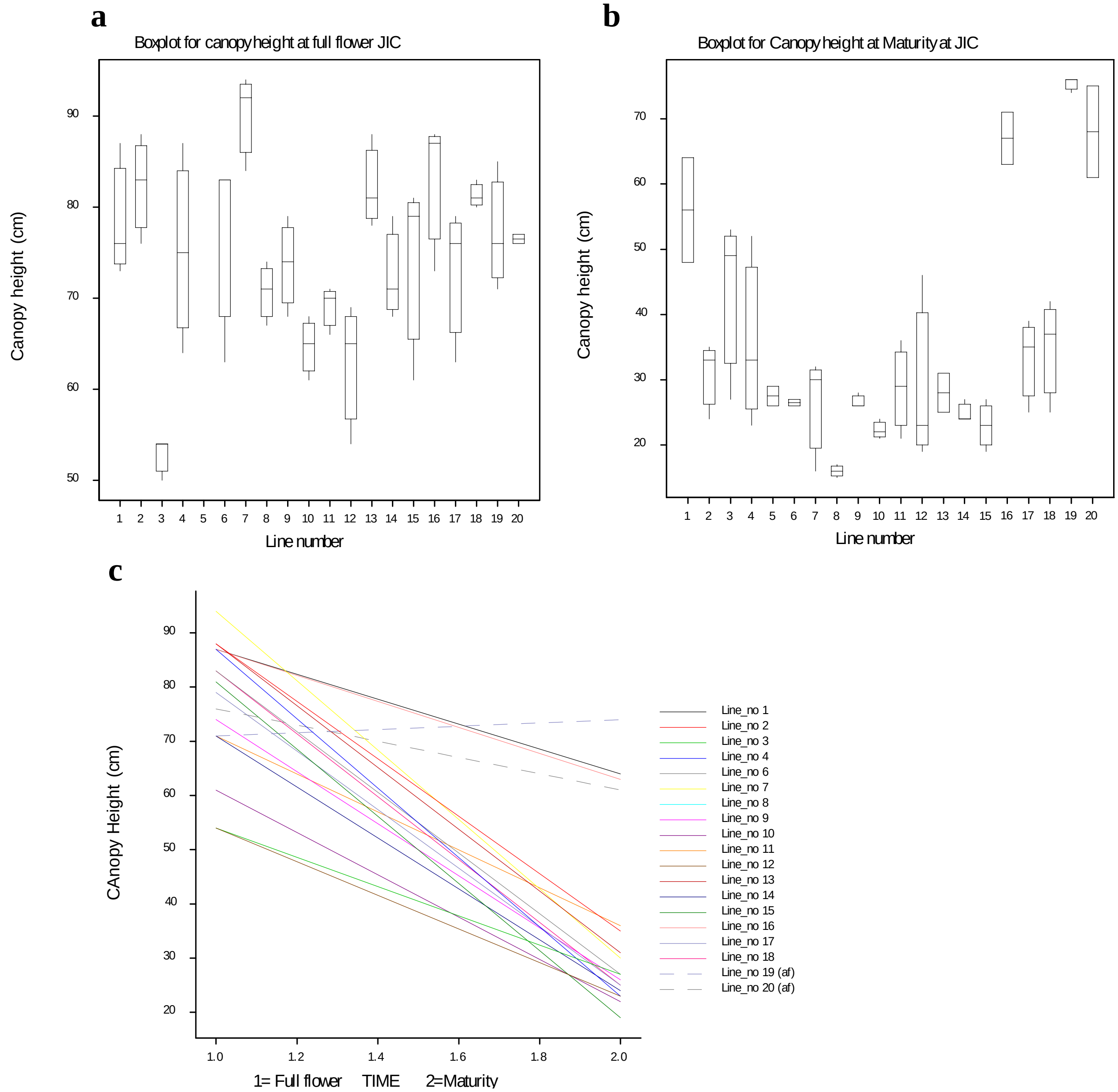
A Y score for standing ability in Table 5 can be assigned to a particular component of lodging in Table 6. Generally a N score in Table 5 corresponds to a dash in Table 6 with a few exceptions. At PGRO, Cooper was scored as NNN for 3 replicates (Table 5), although 1 microplot had a high lean score (Table 6). This lean was attributed to plot position with an anomalous wind exposure, however, rather than a true lean. At JIC, a N score for L16 (JI 2201) was due to the fact that leaning was restricted to the upper portion of the plot canopy and not deemed sufficient to score the plots as having lodged overall.

3.7 Canopy Height

The change in height of the canopy between full flower and maturity can be seen as an integration of the different criteria such as basal sagging, leaning and creeping that were covered in the preceding section. To cover the situation in greater depth, a more detailed study on data for the JIC site was undertaken. Canopy heights at full flower were found to vary significantly between replicates for individual lines (Fig. 4 a). Wide variation between replicates for canopy height at maturity was also evident (Fig. 4 b). While there may be some further development of canopy height through the rest of the season, 2006 was particularly hot during this phase and so additional growth was minimal especially for the later flowering lines.
The plotting of a line between the canopy height at full flower and maturity for a single replicate plot of each line produces a slope that illustrates the changes during the fruiting period of the

crop (Fig. 4 c). This is the period when the weight of the developing seeds and pods adds significantly to the loading on the lower canopy. The first thing to be noted is the performance of the two afila lines (L19 Bilbo and L20 Cooper which exhibit the shallowest slopes). L 19 Bilbo maintains a slight +ve slope while L 20 Cooper exhibits a shallow –ve slope. All the ‘exotic’ lines present –ve slopes.

Fig. 4. Canopy heights for lines grown at JIC, a. Boxplots for canopy heights at full flower, b. canopy heights at maturity and c. Change in canopy height from full flower to maturity for a single plot.



The least –ve and smallest in terms of proportional change are those of L1 (JI 15) and L16 (JI 2201). An examination of how these responses have come about within these two lines highlights some important differences. JI 15 has long internodes and is relatively early flowering (node 8). Its growth is typified by the slow development of pods, which has the consequence that the stems continue growing in length. The final mean stem length for inner plants was

141cm. The replicate in question was recorded as both leaning (2) and creeping (2) (Table 5) so the continued creeping growth counteracted the significant lean in the canopy. The final canopy height of 64cm was less than half the length of stem. The situation for L16 (JI 2201) is a different scenario. Flowering at node 14, the line continues to grow but not to the extent of L1 (final mean stem length from middle plants of 81.2cm). This line scored the lowest lean (424) of all the exotic lines (Table 6).

Another way of approaching this is to calculate the canopy height at maturity as a % of the stem length of harvested plants (Table 7). On this basis L 16 (2201) is again identified as the exotic with the highest score and rank position but the 2nd in ranking is L11 (JI 813) and not L1 (JI 15) which was ranked 3rd among exotics, although the absolute measurements between these two were close. The line with the steepest slope in Figure 4c was L 6 (JI 216) which ranked 17th overall in Table 7.

Table 7. Canopy height at maturity as a % of stem length and rank position for replicate 1 at JIC.

Line	**JIC**	**Rank position**
(1) JI 15	**47**	**5**
(2) JI 45	**40.8**	**7**
(3) JI 181	**43**	**6**
(4) JI 188	**24**	**13**
(5) JI 201	**23**	**14**
(6) JI 216	**18.2**	**17**
(7) JI 228	**18.3**	**16**
(8) JI 281	**36.3**	**8**
(9) JI 284	**21.1**	**15**
(10) JI 399	**29.7**	**11**
(11) JI 813	**49**	**4**
(12) JI 1089	**31**	**9**
(13) JI 1194	**30.5**	**10**
(14) JI 1428	**16.9**	**18**
(15) JI 2105	**16.3**	**19**
(16) JI 2201	**61.7**	**3**
(17) JI 2551	**27.7**	**12**
(18) JI 2605	**29.7**	**11**
(19) Bilbo	**98.6**	**1**
(20) Cooper	**92.4**	**2**

Overall measurement of canopy height at flowering and maturity is quick to obtain and provides comparable data to that obtained from measuring canopy height at maturity and stem length of sampled plants.

3.8 Biomass (inner plants)

Five plants were harvested from all inner and outer microplots (triplicates at three sites) for comparison of agronomic characters. Inner plant biomass for lines at PGRO ranged from 76g for L19 (Bilbo) down to 25g for L 2 (JI 45) in Table 8a. At NIAB the range varied from 66g for L19 (Bilbo) down to 10.31g for L3 (JI 181). The range of values at JIC were all significantly lower than the other two sites ranging from 43.12g for L16 (JI 216) down to 14.52g for L2 (JI 45). With large differences between lines and across sites, it is not surprising that the 2 way ANOVAR resulted in lines and sites being highly significant (Table 8b).

Table 8. Inner plant biomass (dry weight) comparisons. a. Data for all lines on thee sites. Site 1= PGRO, 2=NIAB and 3=JIC, b. 2 way ANOVAR.

a. Inner Plant Biomass

Line_no	1	2	3	4	5
Site					
1	44.47	25.07	34.10	52.33	45.03
2	36.73	28.98	10.31	35.84	61.11
3	22.02	14.52	22.77	22.97	22.21

Line_no	6	7	8	9	10
Site					
1	54.67	50.87	37.40	61.83	54.37
2	84.52	43.61	14.91	61.63	35.55
3	19.33	26.86	21.85	20.94	25.26

Line_no	11	12	13	14	15
Site					
1	54.63	34.27	69.67	39.13	59.33
2	50.60	21.83	53.66	23.60	57.23
3	41.75	29.10	28.95	30.83	15.06

Line_no	16	17	18	19	20
Site					
1	70.97	31.57	35.03	76.00	68.87
2	48.51	26.25	35.70	66.27	59.39
3	43.12	21.19	34.47	40.01	39.11

Minimum standard error of difference	9.83
Average standard error of difference	9.94
Maximum standard error of difference	12.04

b. Analysis of variance

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Site ignoring Line_no	2	16380.7	8190.3	56.54	< 0.001
Site eliminating Line_no	2	16183.6	8091.8	55.86	< 0.001
Line_no ignoring Site	19	23880.6	1256.9	8.68	< 0.001
Line_no eliminating Site	19	23683.5	1246.5	8.61	< 0.001
Site.Line_no	38	13476.8	354.7	2.45	< 0.001
Residual	117	16947.2	144.8		
Total	176	70488.2	400.5		

Conversion of the data to ranks overcomes the differences in actual values and reveals that L 19 (Bilbo) was the most highly ranked line for biomass across all three sites (Table 9). Two other high ranking lines that stand out are L 20 (Cooper) and L 16 (JI 2201). Three lines were low ranked across all three sites. L2 (JI 45) ranked 20, 15, 20, L 7 (JI 228) ranked 11, 10, 9 and L17 (JI 2551) ranked 19, 16, 16. Medium ranking lines were L 7 (JI 228) and L 14 (JI 1428). There are numerous examples of lines which have a high or low rank on two sites but the rank at the third is in the alternate group (e.g. L 6 (JI 216) ranked 7,1,18), L 15 (JI 2105) ranked 5,6,19), L 5 (JI 201) ranked 12, 4, 18) and L 9 (JI 284) ranked 5, 3, 17).

Table 9. Ranks of inner plant biomass (dry weight). Site 1= PGRO, 2=NIAB and 3=JIC.

Ranks of Inner Plant Biomass

Line_no	1	2	3	4	5
Site					
1	13	20	18	10	12
2	11	15	20	12	4
3	14	20	12	11	13

Line_no	6	7	8	9	10
Site					
1	7	11	15	5	9
2	1	10	19	3	14
3	18	9	15	17	10

Line_no	11	12	13	14	15
Site					
1	8	17	3	14	6
2	8	18	7	17	5
3	2	7	8	6	19

Line_no	16	17	18	19	20
Site					
1	2	19	16	1	4
2	9	16	13	2	6
3	1	16	5	3	4

3.9 Seed Yield (inner plots)

Seed yield from the inner plants (sampled as in section 3.8 above) varied between lines at every site. At PGRO the highest yield was 48.27g for L 19 (Bilbo) down to 10.2g for L 5 (JI 201) (Table 10a). At NIAB the highest yield was 47.49g for L19 (Bilbo) and the lowest was 3.11g from L3 (JI 181). As with biomass, the values for the lines at JIC were significantly lower with the highest yield of 19.48g from L19 (Bilbo) and the lowest at 1.84g from L15 (JI 2105). The 2 way ANOVAR again showed highly significant effect for lines and sites (Table 10b).

Table 10. Inner plant seed weight (dry weight) comparisons. a. Data for all lines on thee sites. Site 1= PGRO, 2=NIAB and 3=JIC, b. 2 way ANOVAR.

a. Inner Plant Seed

Line_no	1	2	3	4	5
Site					
1	20.87	11.13	15.43	22.07	10.20
2	16.27	13.21	3.11	19.07	26.44
3	5.20	6.28	11.82	8.82	3.37

Line_no	6	7	8	9	10
Site					
1	27.60	15.90	15.53	30.60	31.17
2	47.49	20.21	4.74	29.43	22.78
3	2.76	6.98	8.80	4.82	11.09

Line_no	11	12	13	14	15
Site					
1	29.70	15.23	38.83	13.20	19.00
2	26.96	8.63	31.46	10.27	24.75
3	16.03	15.05	11.57	8.32	1.84

Line_no	16	17	18	19	20
Site					
1	32.17	13.93	14.07	48.27	36.83
2	21.65	12.98	15.16	38.10	31.72
3	18.05	6.99	14.31	19.48	17.29

Minimum standard error of difference	4.975
Average standard error of difference	5.389
Maximum standard error of difference	6.538

b. Analysis of variance

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Rep_no	2	86.27	43.13	1.02	0.365
Site ignoring Line_no	2	5839.56	2919.78	68.90	< 0.001
Site eliminating Line_no	2	5849.93	2924.96	69.02	< 0.001
Line_no ignoring Site	19	9453.82	497.57	11.74	< 0.001
Line_no eliminating Site	19	9464.19	498.12	11.75	< 0.001
Site.Line_no	38	5775.72	151.99	3.59	< 0.001
Residual	115	4873.44	42.38		
Total	176	26039.18	147.95		

Converting seed yield to ranks, L19 (Bilbo) provided the highest ranking across all three sites with L20 (Cooper) also ranking highly across all sites (Table 11). Lines ranking poorly over all sites included L2 (JI 45) and L 17 (JI 2551). As with biomass, there were lines which ranked closely across 2 sites and at high contrast on the third (e.g. L16 (JI 2201) ranked 4, 10, 2, (L 9 (JI 284) 6, 5, 17 and L6 (JI 216) ranked 8, 1, 19).

Table 11. Ranks of inner plant seed dry weight. Site 1= PGRO, 2=NIAB and 3=JIC.

Ranks of Inner Plant Seed

Line_no	1	2	3	4	5
Site					
1	10	19	14	9	20
2	13	15	20	12	7
3	16	15	7	10	18

Line_no	6	7	8	9	10
Site					
1	8	12	13	6	5
2	1	11	19	5	9
3	19	14	11	17	9

Line_no	11	12	13	14	15
Site					
1	7	15	2	18	11
2	6	18	4	17	8
3	4	5	8	12	20

Line_no	16	17	18	19	20
Site					
1	4	17	16	1	3
2	10	16	14	2	3
3	2	13	6	1	3

3.10 Harvest Index

Harvest index (HI) is the ratio of seed to whole plant above ground biomass expressed as a percentage. HI values for inner plants at PGRO varied from 64.33 for L19 (Bilbo) down to 23.52 for L 5 (JI 201) (Table 12). This high value for Bilbo is based on three replicate plots that include one where an anomalous low value had been recorded for oven-dried haulm and pod biomass. Omitting this replicate gives a mean of 56.14, a value that is more realistic and has been used in Figure 5 and Table 14 below. At PGRO, thirteen lines showed a HI higher than 40%. At NIAB the highest HI of 58.62 was recorded for L13 (JI 1194) and the lowest was 29.14% for L3 (JI 181). Fifteen lines achieved a HI of over 40%. The data at JIC delivered the highest HI value of 52.18 for L3 (181) and the lowest of 9.71 for L5 (JI 201). Only 7 lines on the JIC site achieved a HI over 40%.

Table 12. Inner plant harvest index, calculated on a dry weight basis. a. Data for all lines on thee sites. Site 1= PGRO, 2=NIAB and 3=JIC, b. 2 way ANOVAR. (See text for discussion of the Bilbo Site 1 value shaded in grey).

a. Inner Plant Harvest Index (%)

Line_no	1	2	3	4	5
Site					
1	47.04	27.65	45.59	37.31	23.53
2	43.74	44.33	29.14	53.17	43.52
3	21.11	38.45	52.18	39.54	9.71

Line_no	6	7	8	9	10
Site					
1	50.08	30.71	41.13	49.70	57.29
2	56.43	45.88	29.42	48.97	50.14
3	14.28	25.34	39.53	20.57	43.72

Line_no	11	12	13	14	15
Site					
1	54.51	44.87	56.15	32.95	33.79
2	53.21	38.95	58.62	43.41	38.94
3	37.57	51.06	35.10	25.48	12.59

Line_no	16	17	18	19	20
Site					
1	45.52	43.45	36.70	64.34	53.63
2	44.49	45.96	37.88	57.05	53.10
3	42.38	33.39	41.08	48.10	44.79

Minimum standard error of difference	6.665
Average standard error of difference	6.744
Maximum standard error of difference	8.163

b. Analysis of variance

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Site ignoring Line_no	2	4899.96	2449.98	36.77	< 0.001
Site eliminating Line_no	2	4694.35	2347.18	35.22	< 0.001
Line_no ignoring Site	19	10462.17	550.64	8.26	< 0.001
Line_no eliminating Site	19	10256.56	539.82	8.10	< 0.001
Site.Line_no	38	9693.45	255.09	3.83	< 0.001
Residual	117	7796.18	66.63		
Total	176	32646.15	185.49		

HI is already a relative assessment of partitioning but it is still helpful to converting HI to ranks to see the relationships a little easier. L19 (Bilbo) was consistently the highest ranking line across all three sites followed by L20 (Cooper) (Table 13). The most consistently low lines for HI were L5 (JI 201) ranked 20, 13, 20, L14 (JI 1428) ranked 17, 15, 14 and L15 (JI 2105) ranked 16, 16, 19. Other lines showed similar values across 2 sites but were highly contrasting in the third (e.g. L6 (JI 216) ranked 6, 2, 18, L13 (JI 1194) ranked 3, 1, 12 and L12 (JI 1089) ranked 11, 17, 2).

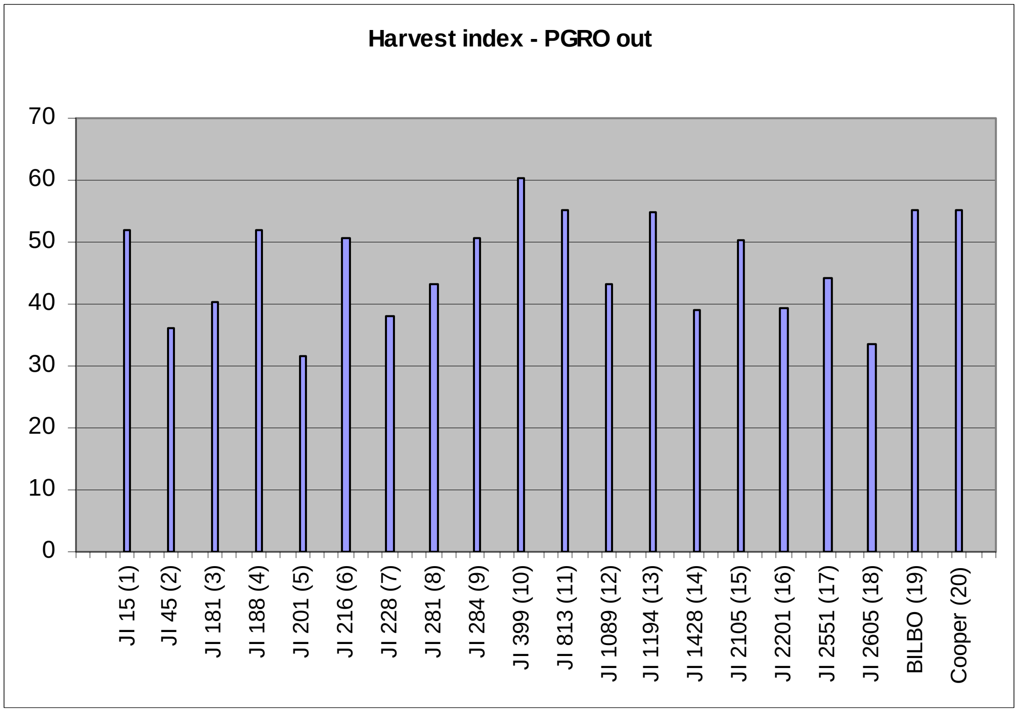
Table 13. Ranks of inner plant harvest index. Site 1= PGRO, 2=NIAB and 3=JIC.

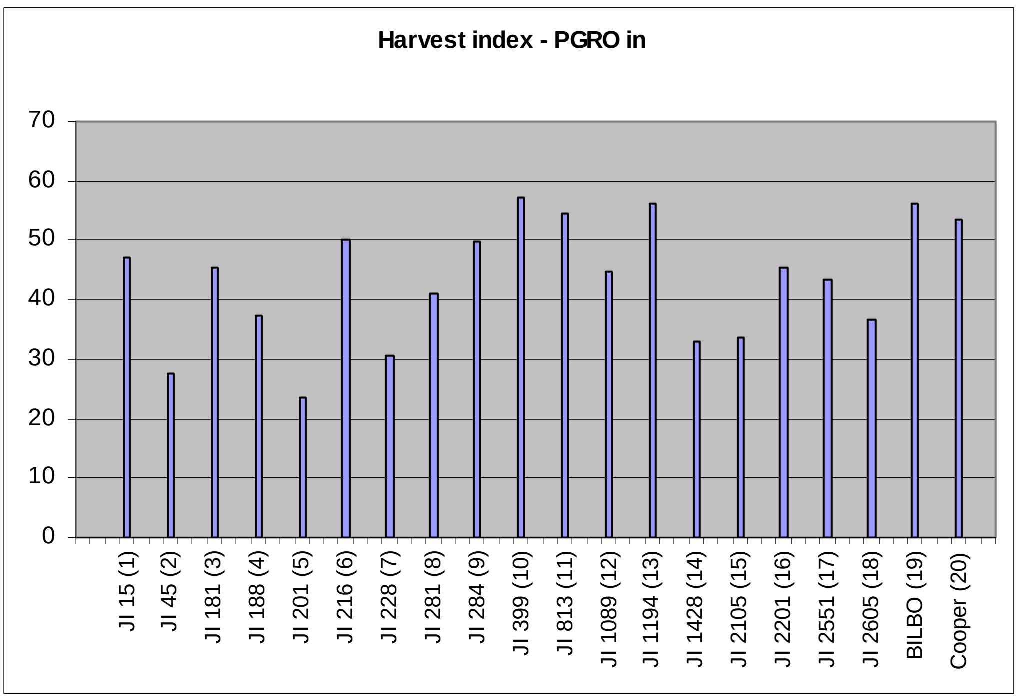
Ranks of Inner Plant Harvest Index

Line_no	1	2	3	4	5
Site					
1	8	19	9	14	20
2	14	12	20	5	13
3	16	10	1	8	20
Line_no	6	7	8	9	10
Site					
1	6	18	13	7	2
2	2	10	19	8	7
3	18	15	7	17	5
Line_no	11	12	13	14	15
Site					
1	4	11	3	17	16
2	4	17	1	15	16
3	11	2	12	14	19
Line_no	16	17	18	19	20
Site					
1	10	12	15	1	5
2	11	9	18	3	6
3	6	13	7	3	4

The results presented in the above section compared the HI from the inner plants only. The remaining results show the HI results for both inside and outside plants grown at the three sites. Figure 5 shows a comparison of the harvest index calculated for the 20 lines grown in microplots at PGRO, based on analysis of the five plants on the outer edge or inside every microplot.

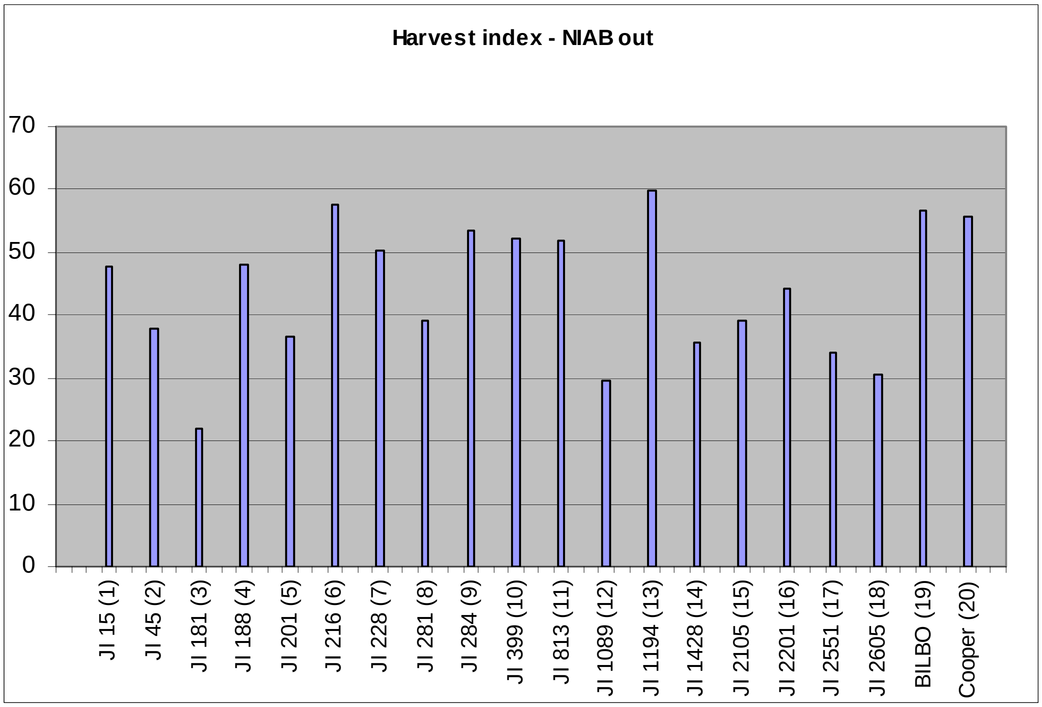
Fig. 5. Harvest index (HI) calculated for pea lines. HI = seed weight as a percentage of the total plant harvest (seeds plus oven-dried haulm and pods) for 5 plants on the outer edge (out) or inside (in) every microplot at PGRO in 2006.

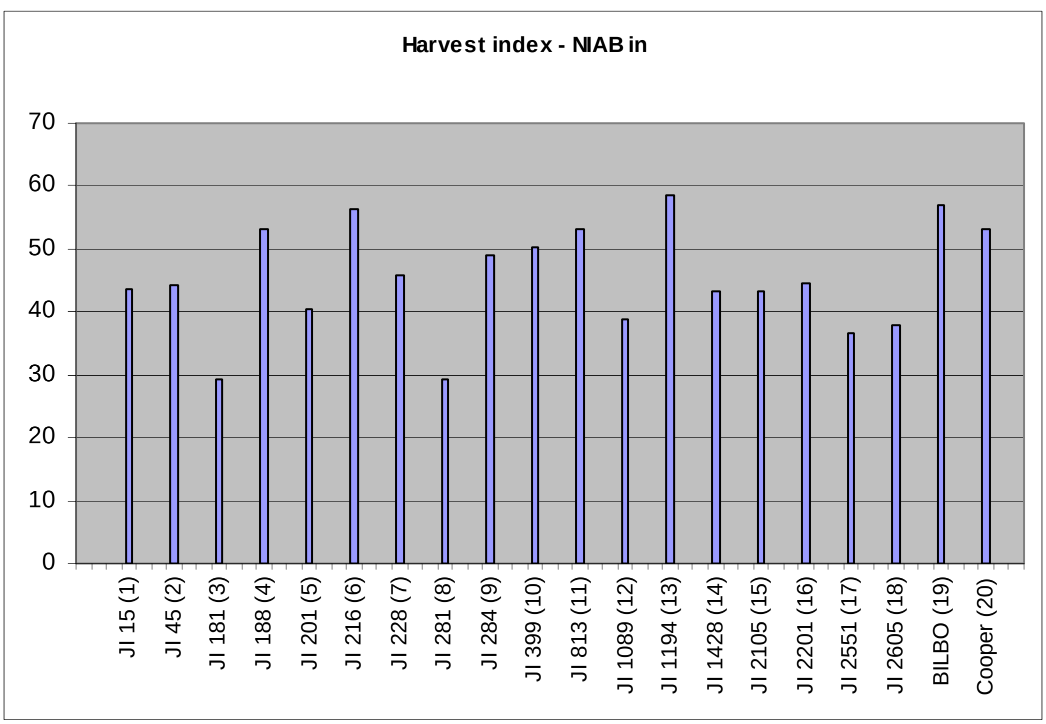




A comparison of the harvest index of plants from the centre and outside of the plot (Fig. 5) shows that there is some consistency in the data acquired for particular lines, regardless of their location in the plot. It is also apparent that some of the exotic material has a harvest potential comparable to the commercial cultivars of >50%. In contrast, L5 (JI 201) for example yielded poorly regardless of location.

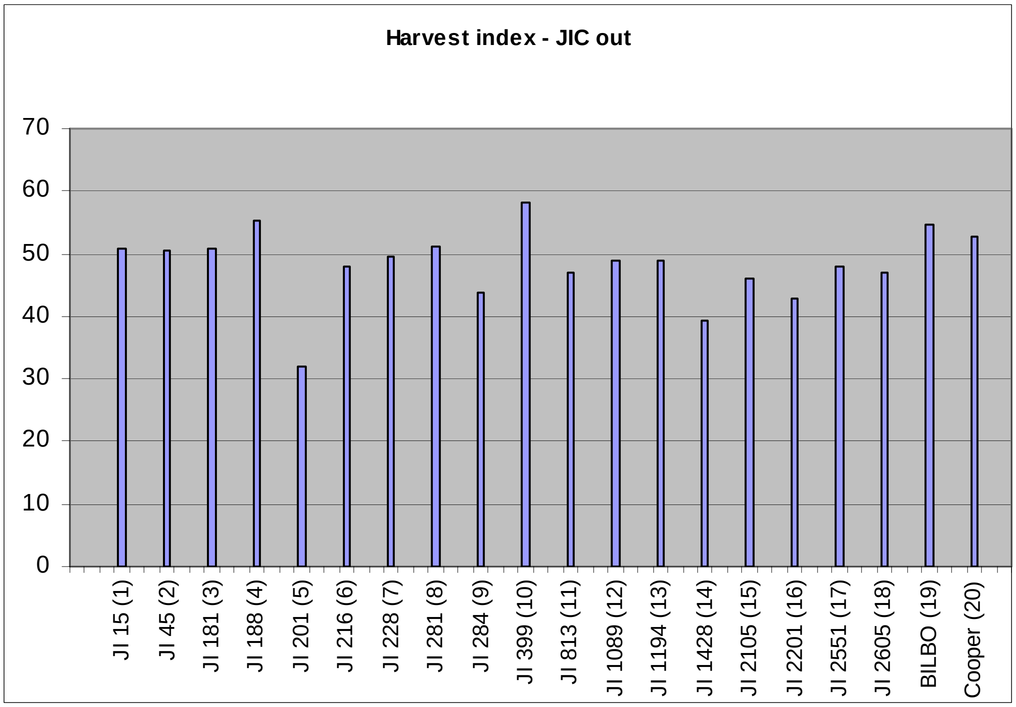
Fig. 6. Harvest index (HI) calculated for pea lines. HI = seed weight as a percentage of the total plant harvest (seeds plus oven-dried haulm and pods) for 5 plants on the outer edge (out) or inside (in) every microplot at NIAB in 2006.





At NIAB, again there is a consistency among lines, regardless of their position within the microplot. In addition, some lines show results comparable to the commercial lines. These include JI 188, JI 216, JI 284, JI 399, JI 813 and JI 1194, which apart from JI 188 all showed good HI values in the PGRO plots (Fig. 6).

Fig. 7. Harvest index (HI) calculated for pea lines. HI = seed weight as a percentage of the total plant harvest (seeds plus oven-dried haulm and pods) for 5 plants on the outer edge (out) or inside (in) every microplot at JIC in 2006.



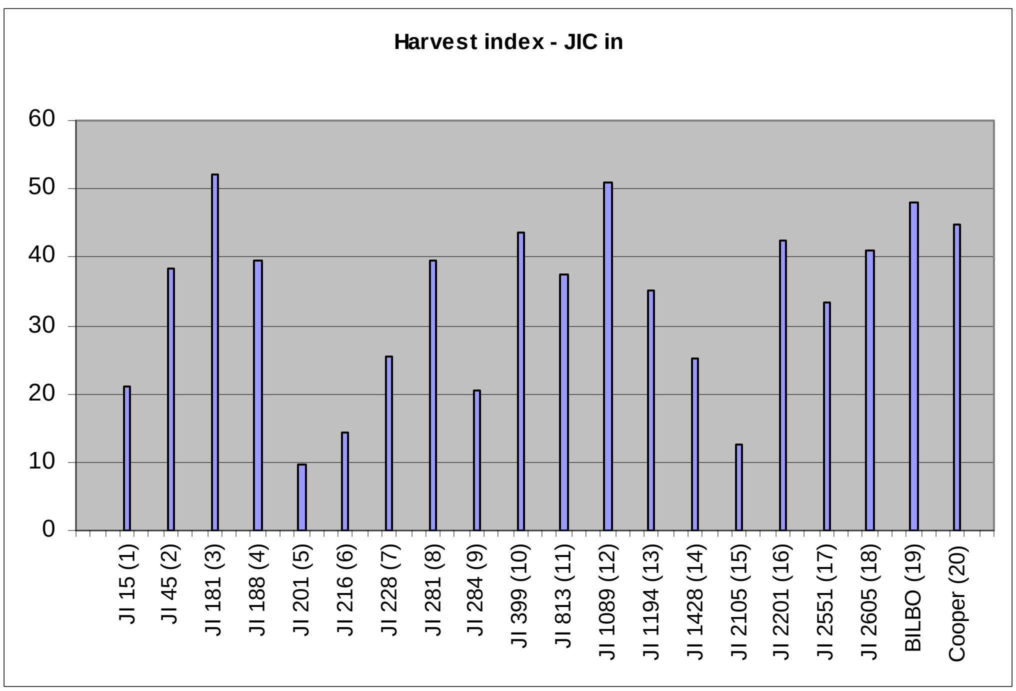


Fig. 7 shows the data acquired in a similar way for the plants grown at JIC. Here there was less consistency among plants harvested from the outside relative to those inside, and data for one line (JI 1428) are missing. The lack of agreement here between the two positions within the microplot may reflect the different soil type and/or method of planting. Based on the performance of the outside plants alone, a greater number of lines showed HI values that were comparable to those of the commercial lines. These included JI 188, JI 216, JI 399, JI 813 and JI 1194, noted above as the best lines at NIAB, on the basis of harvest index (Fig. 6).

A plot of the harvest indices of middle versus outer plants for all 20 lines across the three sites clearly shows the greater consistency of middle to edge performance for the lines at PGRO and NIAB (Fig. 8) and lower inner HI values for lines grown at JIC. Line numbers for JIC lines falling outside the range of values for NIAB and PGRO are presented.

Fig. 8. Mean harvest indices (%) for inner plants versus outer plants for 20 lines from all three growing sites. The red line represents a 1 to 1 relationship.

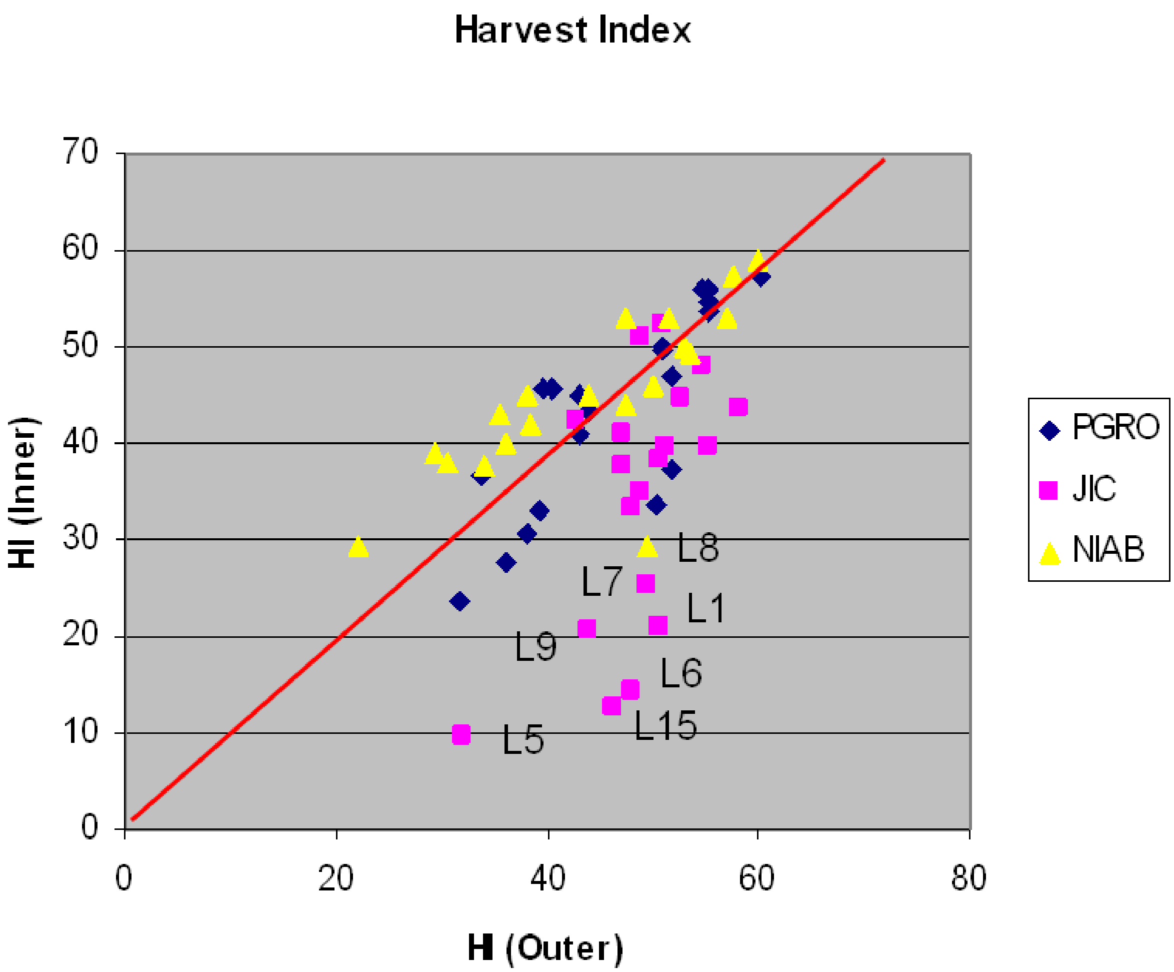


Table 14 presents the actual HI values and highlights those lines where the values from the inner plants exceeded those of the outer plants. L3 (JI 281) showed a higher HI value for inner compared with outer plants across all three sites. L12 (JI 1089) also had higher HI for inner plants at three sites. L 16 (JI 2201), L18 (JI 2605) and Bilbo gave higher HI for inner plants at NIAB and PGRO.

Table 14. Mean harvest indices (HI as %) for 5 inner and 5 outer plants for 20 lines for all three sites. Shaded cells indicate where inner HI was higher than for the outer plants.

Line	JIC		PGRO		NIAB	
	outer	inner	outer	inner	outer	inner
1	50.75	21.12	51.78	47.04	47.78	43.71
2	50.63	38.45	36.04	27.63	38.00	44.37
3	50.89	52.18	40.33	45.59	21.91	29.17
4	55.35	39.54	51.80	37.31	48.07	53.19
5	31.93	9.71	31.70	23.53	36.50	40.25
6	48.08	14.28	50.79	50.08	57.69	56.43
7	49.56	25.34	38.18	30.71	50.12	45.89
8	51.08	39.53	43.19	41.13	39.19	29.37
9	43.95	20.57	50.78	49.70	53.57	48.98
10	58.32	43.73	60.34	57.29	52.19	50.14
11	47.01	37.57	55.16	54.51	51.99	53.22
12	48.84	51.06	43.07	44.87	29.60	38.98
13	48.90	35.10	54.64	56.15	59.75	58.65
14	39.29	25.48	39.14	32.93	35.76	43.42
15	46.14	12.59	50.19	33.79	39.13	43.23
16	42.74	42.38	39.42	45.52	44.31	44.52
17	47.87	33.39	44.06	43.43	33.95	45.94
18	47.13	41.09	33.69	36.70	30.58	37.89
19	54.58	48.10	55.31	56.14	56.67	57.08
20	52.65	44.79	55.24	53.53	55.66	53.11

Appendix I List of selected lines for 2006 micro-plot trial.

20 lines comprising 18 exotic germplasm lines and two commercial cultivars as controls.

Line No.	JI No	NAME
1	15	WBH 1458
2	45	P.TRANSCAUCASICUM
3	181	KEERAU PEA
4	188	WIRAIG
5	201	P.THEBAICUM
6	216	KANAWARI
7	228	P.SATIVUM-BOLIVIA
8	281	P.SATIVUM-ETHIOPIA
9	284	P.SATIVUM-AFGHANISTAN
10	399	CENNIA
11	813	YELLOW POLLEN-yp
12	1089	P.ELATIUS
13	1194	MISOG-1:CONVENTIONAL
14	1428	P.TIBETANICUM
15	2105	P.ELATIUS
16	2201	P.ELATIUS
17	2551	P. SATIVUM SIBERIACUM
18	2605	P. SPECIOSUM-LIBYA
19		Bilbo
20		Cooper

Appendix II Experimental design

Complete randomised block design. 60 plots comprising of 3 blocks of 20 lines with 1 replicate per block (appendix 1 and attached xls file). *This design allows greater flexibility for plot layout than a single block with three replicates*.
Blocks to be run in series or parallel according to land availability.

Plot size 1.1m^2
With a minimum of 20cm between plots along the drill. Double wheelings between drill rows to allow ease of access for observations.

Plots to be supported along the rows as discussed.

Plot random order number sequences

Line no	Rep	Random order
1	1	4
2	1	12
3	1	7
4	1	17
5	1	19
6	1	14
7	1	16
8	1	5
9	1	13
10	1	2
11	1	8
12	1	10
13	1	11
14	1	9
15	1	1
16	1	6
17	1	15
18	1	18
19	1	3
20	1	20
1	2	2
2	2	1
3	2	14
4	2	15
5	2	11
6	2	3
7	2	17
8	2	10
9	2	8
10	2	5
11	2	9
12	2	12
13	2	16
14	2	4
15	2	19
16	2	20
17	2	6

18	2	7
19	2	13
20	2	18
1	3	4
2	3	3
3	3	2
4	3	5
5	3	17
6	3	10
7	3	15
8	3	13
9	3	12
10	3	8
11	3	6
12	3	20
13	3	14
14	3	11
15	3	1
16	3	7
17	3	19
18	3	9
19	3	16
20	3	18

An example for a 5 by 4 block of plots.
Block 1 where Plot number in Red, Line number in *italics*.

1 ***L 15***	**2** ***L 10***	**3** ***L 19***	**4** ***L 1***	**5** ***L 8***
6 ***L 16***	**7** ***L 3***	**8** ***L 11***	**9** ***L 14***	**10** ***L 12***
11 ***L 13***	**12** ***L 2***	**13** ***L 9***	**14** ***L 6***	**15** ***L 17***
16 ***L 7***	**17** ***L 4***	**18** ***L 18***	**19** ***L 5***	**20** ***L 20***

Appendix III Score Sheet

SPECIES : PEAS						SOWING DATE :				
VARIETY :						PLOT NO :			REP NO :	
EMERGENCE DATE	Start					PLANT POPULATION				
	50%									
VIGOUR (1=very poor) (3=good) (5=excellent)	1	2	3	4	5	FLOWERING DATE	50%			
							Full Flower			
							Out of flower			
EARLY BASAL BRANCHING	Yes			No		CANOPY HEIGHT	@ Full Flower			
COLD TOLERANCE	Yes			No		LODGING	YES		NO	
MATURITY DATE						Basal Sag	1	2	3	4	5
						Leaning	1	2	3	4	5
HARVEST DATE						Creeping Habit	1	2	3	4	5
HVST DATA	5 OUTSIDE PLANTS					5 INSIDE PLANTS				
No Vegetative Nodes										
No Flowering Nodes										
Haulm Length										
No Pods / Plant										
Total Peas / Pod										
	BRANCHES									
No Pods / Plant										
Total Peas / Pod										
	Yield at Harvest		Yield Oven Dried			Yield at Harvest		Yield Oven Dried		
Seed Weight										

Weight Haulm + Shelled Pods				
Comments and overall assessment (1-9)				1 2 3 4 5 6 7 8 9