

1 Sources of variation for sustainable field pea breeding

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3 A. Paula Rodiño ^{1,*}, Josefina Hernández-Nistal ², Maria Hermida ³, Marta Santalla ¹, &
4 Antonio M. De Ron ¹

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6 ¹ Plant Genetic Resources Department, Misión Biológica de Galicia - CSIC, P. O. Box 28,
7 36080 Pontevedra, Spain (*author for correspondence, e-mail: aprodino@mbg.cesga.es)

8 ² Department of Plant Physiology. University of Santiago de Compostela. Avda. Carballo
9 Calero s/n. 27002 Lugo, Spain

10 ³ Laboratory of Mouriscade. Servicio Agrario. Diputación Provincial de Pontevedra.
11 Finca Mouriscade. Lalín, Spain

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2 **Summary**

3 The pea crop (*Pisum sativum* L.) is a convenient source of plant protein for animal feeding.
4 The objective of this research was to evaluate field pea breeding lines for agronomic
5 performance and seed quality focussed to their use in a sustainable production. Thirty five
6 field pea breeding lines and six elite cultivars were evaluated for their agronomic value in
7 field in Spain upon 20 traits related to flower, cycle, plant architecture, productivity and
8 seed quality. The lines showed significant differences in all the quantitative traits evaluated
9 and three of them, namely MB-0307, MB-0308, and MB-0319 were chosen to be
10 evaluated, together with the advanced cultivar ZP-1233, in field and in growing chamber
11 for agronomic performance, seed quality and ability for sustainable production. The four
12 accessions displayed high seed protein content that had significant effect of cropping
13 density with averages of 253.6 g kg⁻¹ under low cropping density of 60 plants m⁻² and
14 259.1 g kg⁻¹ under high cropping density of 90 plants m⁻², therefore, the low cropping
15 density should be regarded as the most convenient. Average yield of the lines MB-0307,
16 MB-0308 and MB-0319 and the cultivar ZP-1233 was fair (197.5 g m⁻²), probably due to
17 the absence of fertilizers and irrigation, aiming for the sustainability of the crop.
18 Intercropping with rye and herbicide application resulted in no differences on the seed
19 yield; therefore, the ability of the breeding lines to grow without herbicide seems to be
20 demonstrated, while the germination of the seeds at low temperature was very good. These
21 results indicate that field pea could be a new protein crop in the North of Spain to satisfy
22 the demand of plant protein for animal feed, based upon adapted breeding lines that
23 combine the ability for growing under sustainable conditions with other desirable
24 agronomic traits maintaining an adequate productivity.

1 **Introduction**

2 Pea (*Pisum sativum* L.), a native legume from the Southwest of Asia, was one of the crops
3 early cultivated by man, and wild pea can still be found in Afghanistan, Iran and Ethiopia.
4 Pea is an annual, cool-season, pulse (legume) crop. Cultivation of pea has lead to a gradual
5 separation of types: for vegetable use, for seed and fodder (field pea) (Duke 1981, Santalla
6 et al. 2001), and the edible podded types which have evolved recently. Dry pea seeds have
7 high levels of the essential amino acids lysine and tryptophan, which appeared in low
8 amounts in cereal grains. Consequently, dry pea can supplement the low amount of protein
9 present in food and feed processed from cereal grains. Pea flour is valued not only as a
10 plant protein source but also because is unique functional properties. The use of plant
11 proteins as functional ingredients in the food and feed industry is increasing and special
12 attention has been paid to the use of peas because they are already accepted as a part of the
13 human and animal diet throughout the world. Pea also contains proteases, tannins, lectins,
14 etc. which may reduce livestock feed gain when their concentration is high in the diet.
15 However, it has been shown that partial or complete replacement of soybean meal with pea
16 screenings (in a barley diet for hogs) did not reduce growth rate or efficiency of feed
17 conversion.

18 There is a chronic lack of home-produced plant protein sources for the animal feed
19 industry in Europe reaching 76% deficit in 2003/2004 compared to 73% in 1999/2000 and
20 62% in 1990/1991 (AEP 2007). In Spain $43 \cdot 10^3$ ha of field pea crop averaged 1.34 Mg ha^{-1}
21 ¹. Therefore, acreage and yield are very low compared to other European countries such as
22 France ($436 \cdot 10^3$ ha, 4.45 Mg ha^{-1}), United Kingdom ($85 \cdot 10^3$ ha, 3.50 Mg ha^{-1}) or Germany
23 ($141 \cdot 10^3$ ha, 2.86 Mg ha^{-1}) (AEP 2004).

24 The pea plant requires cool, moist growing conditions and can withstand heavy
25 frost; however, it succumbs quickly to heat, especially if combined with high humidity.

1 The use of commercial improved pea varieties is not a common practice in many areas of
2 Spain which explains the low yield in this country. The main reason is the lack of varieties
3 adapted to the humid conditions of some temperate areas as in the North and Northwest of
4 Spain (Caminero 2002). Additionally, other limiting factors are diseases caused by bacteria
5 (*Pseudomonas syringae* pv *pisi*) and fungi (*Erysiphe polygoni*, *Mycosphaerella pinodes*,
6 *Fusarium* spp., *Aphanomyces euteiches*) as well as infection by crenate broomrape
7 (*Orobanche crenata*) (Rubiales et al. 2005, Tivoli et al. 2006).

8 Most pea varieties grown in these Spanish regions are mixtures of pure lines and
9 can be considered as unimproved adapted landraces (Santalla et al. 2001). Many of them
10 have medium to long vines, medium size white flowers and cream or pale green coloured
11 seeds with a smooth seed coat. The farmers save some seeds from the harvest for planting
12 the next year. These traditional landraces or heirloom cultivars are an important genetic
13 resource for plant breeders because of their considerable genotypic variation and their
14 adaptation to environmental conditions after many years of cultivation (Amurrio et al.
15 1993).

16 The increasing interest to search for alternative sources of plant protein for animal
17 feeding gives an opportunity for new uses of an ancient crop such as the pea. The Spanish
18 pea collections were evaluated under different conditions in order to display the different
19 uses of the accessions and to make possible the use of this germplasm for production and
20 breeding (Amurrio et al. 1995, Amurrio et al. 2000, Santalla et al. 2001, Caminero 2002).
21 Additionally, the cropping system should be assessed aiming for the crop sustainability by
22 enhancing the use of local resources and having less need for external inputs (Crozat and
23 Justes 2004).

24 The objective of this research was to evaluate field pea breeding lines for
25 agronomic performance and seed quality focussed to their use in a sustainable production.

1 **Material and Methods**

2 The collection of pea maintained at he Misión Biológica de Galicia - National Spanish
3 Research Council (MBG-CSIC, Pontevedra, Spain) contains 237 accessions (Santalla et al.
4 2001). Some field pea breeding lines were derived by single plant selection within those
5 accessions with an adequate profile for protein content. These lines were the basis for the
6 field pea breeding program described in this research. This research involved three
7 experiments: 1) screening of breeding lines, 2) evaluation of their agronomic performance
8 and seed quality for feed, and 3) assessment for sustainable production.

9 10 *Experiment 1: screening of breeding lines*

11 Thirty-five field pea breeding lines and six commercial cultivars as control were
12 evaluated in two winter field trials in 2000-2001 in Pontevedra (Spain, 42° 26' N, 8° 38' W,
13 20 masl, average temperature 18.6°C, annual rainfall 1600 mm) and Lalín (Spain, 43° 00'
14 N, 7° 33' W, 450 masl, average temperature 11.6°C, annual rainfall 800 mm). The
15 experimental design was a randomized complete block with two replications and 30
16 plants/plot spaced 0.25 m x 0.80 m (experimental cropping density of 5 plants m⁻²).
17 Fertilization and irrigation were not provided. Thirteen quantitative traits were measured or
18 calculated on an average plot basis: first flower (days from sowing to the first flower
19 open), flowering (days from sowing to 50 % of plants have at least one open flower), end
20 of flowering (days from sowing to 50 % of plants end flowering), first dry pod (days from
21 sowing to the first dry pod), seed maturity (days from sowing to 50 % of plants have pods
22 with dry seeds), plant height (measured in centimetres), number of leaflets and number of
23 tendrils, pod length (measured in millimetres), pods plant⁻¹, seeds pod⁻¹, seed diameter
24 (measured in millimetres), and seed weight (g 100 seeds⁻¹). Six qualitative traits were also
25 recorded: flower colour, shape of pod (I=small, straight and obtuse at end, IV=very long,

1 wide and curved at end, V=long, straight with beak at the end) and seed (O=oval,
2 S=spherical, G=without geometrical form), testa and cotyledon colour and cotyledon shape
3 (W=wrinkled, S=straight, SD=straight with dimple) (Amurrio et al. 1993, 1995, Mateo-
4 Box 1961).

5
6 *Experiment 2: evaluation of the agronomic performance and seed quality for feed*

7 After the screening, 24 breeding lines were grown in different sets in farmer fields
8 in 10 locations (six under organic farming and four under conventional practices) in the
9 Northwest of Spain in 2001-2002. This research permitted to point out three lines, namely
10 MB-0307, MB-0308 and MB-0319. They were evaluated, together with the advanced
11 cultivar ZP-1233 as control, in winter field trials in 2003, 2004 and 2005 in the season
12 Pontevedra and Lalín according to an experimental design arranged as randomized
13 complete blocks with two replications and two cropping densities: 60 plants m⁻² and 90
14 plants m⁻². Each experimental plot had 25 m². Fertilization and irrigation were not
15 provided. Agronomic value was assessed by five traits as described above: first flower, end
16 of flowering, first dry pod, seed maturity, and seed yield (g m⁻²). The seed quality for feed
17 was evaluated as the content (expressed as g kg⁻¹) of protein, fibre and starch (AOAC,
18 2000).

19
20 *Experiment 3: assessment for sustainable production*

21 This experiment evaluated the ability of the breeding lines MB-0307, MB-0308,
22 and MB-0319, with the cultivar ZP-1233 as a control, for growing under sustainable
23 conditions such as low temperature, competition with weeds and intercropping.

24 The ability for seed germination under cold conditions was evaluated in a growing
25 chamber. The seeds were sown in a sterile medium in plastic seed pots according to an

1 experimental design arranged as randomized complete blocks with three replications and
2 10 seeds for each accession. Growing conditions resembled extreme winter weather
3 conditions in Northern Spain: 12 h days at 5 °C and 12 h nights at -1 °C. Irrigation was
4 provided when needed. The proportion of germination and the heat units accumulation
5 until germination (Baskerville and Emin 1969) being 0°C the threshold temperature were
6 recorded on an average plot basis for each accession.

7 The performance of the four accessions under competition with weeds and
8 intercropping with rye (*Secale cereale* L.) was evaluated in 2005 in a winter field trial in
9 Castro de Rei - Lugo (Spain, 43° 09' N, 7° 29' W, 400 masl, average temperature 11.3°C,
10 annual rainfall 890 mm). The accessions were arranged according to a randomized
11 complete block design with two replications and four treatments: a) control (check), b)
12 intercropping with rye, c) pre-emergence (10 days after sowing) application of 4 L ha⁻¹
13 diluted in 500 L water ha⁻¹ pendimethalin herbicide, and d) post-emergence (40 days after
14 sowing) application of 4 L ha⁻¹ diluted in 500 L water ha⁻¹ pendimethalin herbicide. Each
15 experimental plot had 3 m² with a crop density of 60 plants m⁻² in sole crop and 40 plants
16 m⁻² plus 0.01 kg m⁻² rye seeds. Fertilization and irrigation were not provided. Seed yield
17 and three yield components were evaluated as described above: pods plant⁻¹, seeds pod⁻¹,
18 and seed weight.

19 *Statistical analysis*

20
21 Analyses of variance were performed using the SAS statistical package (SAS
22 Institute 2000) and considering environments as a random factor and lines as a fixed factor.
23 Mean comparisons were performed by Student *t* test according to Steel et al. (1997).

1 **Results**

3 *Screening of breeding lines*

4 The table 1 shows the description of the studied accessions according to six flower, pod
5 and dry seed qualitative traits. Mostly of the accessions (66 %) had white flower and pod
6 type IV (51 %) or I (46 %) having only MB-0034 a pod type V. The six commercial
7 cultivars and 20 lines had no geometrical seeds and only five commercial cultivars had
8 wrinkled cotyledons. The most frequent colours were cream (46 %) for the testa and
9 yellow (85 %) for the cotyledon, showing 18 lines and the cultivar Gloton the association
10 of cream testa and yellow cotyledon.

11 Differences among accessions were significant for all the quantitative traits
12 evaluated (Table 2). Significant differences among locations were found for all traits while
13 accessions by location interaction was significant for first flower, first dry pod, plant
14 height, pod length, pods plant⁻¹, seeds pod⁻¹, seed diameter and seed weight. The
15 coefficients of variation were low except for pods plant⁻¹.

16 The table 3 displays the mean comparison for the quantitative traits evaluated.
17 Earliness is indicated by days to first flower, days to flowering, days to end of flowering,
18 days to first dry pod and days to seed maturity. The lines MB-0034, MB-0050, MB-0052,
19 MB-0109, MB-0315, and MB-0319, and the commercial cultivars Atlas, Lotus, Rondo and
20 Utrillo, had the best global scores for earliness. The architecture of plant was revealed by
21 plant height, number of leaflets and number of tendrils. In the North of Spain, farmers
22 demand medium-tall plants, having as many tendrils as leaflets, to get the best canopy on
23 field. Therefore, the lines MB-0007, MB-0010, MB-0013, MB-0024, MB-0100, MB-0307,
24 MB-0312 and MB-0319, and the commercial cultivars, Alderman and Gloton, displayed
25 adequate plant architecture for field pea production. The productivity was denoted by the

1 yield components such as pod length, pods plant⁻¹, seeds pod⁻¹, and seed diameter and
2 weight. The most productive lines were MB-0013, MB-0014, MB-0015, MB-0307, MB-
3 0308, MB-0309, MB-0310, MB-0312 and MB-0314.

4 5 *Evaluation of agronomic performance and seed quality for feed*

6 The table 4 shows the analysis of variance for three breeding lines, MB-0307, MB-
7 0308, MB-0319, and the advanced cultivar ZP-1233. The effect of years and locations and
8 their interaction were significant for all the traits except for fibre content that presented a
9 significant effect of location, while cropping density had a significant effect for protein and
10 starch. Significant differences among accessions were found for first flower, first dry pod,
11 protein, fibre and starch content. Accession by year interaction was significant for first
12 flower, fibre and starch content while accession by location was significant for fibre as
13 well as accession by year by cropping density and accession by location by cropping
14 density. Average values for the traits evaluated are displayed in table 5. The earliness of
15 the four accessions was very similar, and the protein content of the three breeding lines
16 was higher than the advanced cultivar ZP-1233, while the seed yield showed acceptable
17 values for all the accessions evaluated.

18 19 *Assessment for sustainable production*

20 No significant differences among accessions were found for germination under cold
21 conditions. The 83.3 % of the seeds of the breeding lines MB-0307, MB-0308, MB-0319
22 and the advanced cultivar ZP-1233 germinated well after an average of 54.2 accumulated
23 heat units

24 Under the field conditions of the winter experiment, the advanced cultivar ZP-1233
25 showed a severe lack of adaptation that resulted in no useful data. Therefore, ZP-1233 was

1 disregarded for the data analysis. The table 6 shows significant differences both among
2 treatments for seed weight and among accessions for seeds pod⁻¹ and seed weight and
3 significant interaction accessions by treatments for seed weight. The mean comparison of
4 the accessions under competition with weeds and intercropping with rye is shown in table
5 7. The seed yield was acceptable for the three breeding lines and under the different
6 treatments evaluated.

7

1 **Discussion**

2 The plant phenotype could be only a modest predictor of its genetic potential for breeding,
3 therefore, the valuable genes within germplasm collections should be searched directly,
4 according to Tanksley and McCouch (1997). In the case of complex and adaptive traits,
5 characterization and evaluation data should be useful for the management of germplasm
6 collections (Tohme et al. 1995; Amurrio et al. 2000). Selection of peas in small farms and
7 gardens over a long period of time has contributed to the development of landraces adapted
8 to (specific) particular environments. Pea landraces are sometimes grown as unimproved
9 populations or mixtures in many small farms in the North of Spain and Portugal and they
10 may have multiple uses (Santalla et al., 2001).

11 Pea landraces from different areas of Spain and Portugal have intra-landrace
12 variation both in phenotype and isozyme profile (Amurrio et al. 1993, Varela et al. 1997)
13 that provides an opportunity for breeding for different food and feed purposes. The field
14 pea breeding lines evaluated were selected within landraces that exhibited a good
15 performance in previous studies (Amurrio et al., 1993). Mostly of the lines combined white
16 flower and cream or green testa and yellow or green cotyledon, that are the most
17 appropriated for their use in animal feeding (Mateo-Box 1961).

18 Significant location effect and accessions by locations in the experiment 1 could be
19 due to wide differences between the environmental conditions. Temperature during the
20 cool season was lower in Lalín than in Pontevedra and rainfall was higher in Pontevedra
21 than in Lalín. Similar results were reported by Amurrio et al. (1993) in an evaluation of pea
22 germplasm in quite different environments: greenhouse-winter planting open field-winter
23 planting and open field-spring planting. These results agree with those of Snoad and Arthur
24 (1974), Biarnès (2000), and Magallanes (2000). None of the commercial cultivars
25 evaluated showed a good productivity, based on yield components probably, due to a poor

1 adaptation to the area of production. This indicates the need for using adapted germplasm
2 for field production in this area.

3 The significant differences among lines 24 permitted to choose a set of breeding
4 lines with adequate scores to continue the breeding programme. Eleven breeding lines
5 were disregarded based upon their poor performances, for instance accessions with low
6 values for yield components such as pods plant⁻¹ or with long pods but a low number of
7 seeds per pod. An approach to participatory varietal selection (Witcombe et al. 1996) was
8 made by farmer's assessment of the field pea breeding lines under real farm practices as
9 wide as possible. Compared to conventional plant breeding, participatory varietal selection
10 is more likely to produce farmer-acceptable products, particularly for marginal
11 environments as many on the North of Spain are. In this case, the three breeding lines,
12 namely PHA-0307, PHA-0308 and PHA-0319, gained the consensus of farmers and they
13 were included in the next field and laboratory experiments, together with the advanced
14 cultivar ZP-1233. This advanced cultivar has medium-tall plants and displays conventional
15 leaves. According to Caminero (2002), who reported the evaluation of this cultivar in the
16 central highlands of Spain, ZP-1233 represents a reliable control to compare to the well-
17 adapted breeding lines with conventional leaves too.

18 As expected, years and locations had significant effects and interaction on the
19 agronomic traits evaluated in the experiment 2, but no effect of cropping density was
20 detected for these traits. The major pea seed constituents such as protein, fibre and starch
21 content have the potential to be very interesting ingredients for a variety of food and non-
22 food products, and the three seed quality traits showed significant differences among
23 accessions. The protein content is a valuable character for the use of dry pea in animal
24 feeding (Froidmont and Bartiaux-Thill 2004, Soto-Navarro et al. 2004, Arganosa et al.
25 2006). The three breeding lines, namely MB-0307, MB-0308 and MB-0319 had no

1 differences for this trait but all of them displayed higher protein content than the cultivar
2 ZP-1233. The protein value of these seeds should be regarded as a very good one
3 compared to the average protein content of 239 g kg⁻¹ reported by Gueguen and Barbot
4 (1988). Protein content presented significant effect of cropping density with averages of
5 253.6 g kg⁻¹ under low cropping density of 60 plants m⁻² and 259.1 g kg⁻¹ under high
6 cropping density of 90 plants m⁻². Despite the significance of this difference, it seems that
7 in practical terms the average protein content is similar in both densities maybe because N
8 uptake by plants was not affected by the cropping density when N is not a limiting factor.
9 It means that a cropping density of 60 plants m⁻² result in an adequate canopy and it must
10 be regarded as the most convenient with the additional value of seed saving at sown.

11 Average yield in this experiment was 197.5 g m⁻² that is a fair value compared to
12 370.0 g m⁻² reported by Santalla et al. (2001) and 360.5 g m⁻² by Tar'an et al. (2005).
13 Nevertheless, the agronomic practices should be regarded since in this experiment neither
14 fertilizers nor irrigation were provided aiming for the sustainability of the crop.

15 The field pea crop is not currently established in the North of Spain in spite of the
16 many unproductive lands that could be devoted to this crop, aiming for a sustainable and
17 local plant protein for feed. The results of the experiment 3 were unexpected since only
18 seed weight showed a significant effect of treatments and together with seeds pod⁻¹
19 significant differences among accessions and accession by treatment interaction.
20 Intercropping and herbicide application both in pre-emergence and post-emergence
21 resulted in no differences among the seed yield of the accessions assayed with values quite
22 similar to those obtained in absence of any treatment. Therefore, the ability of the breeding
23 lines to grow in sustainable conditions with no-herbicide seems to be demonstrated. Crozat
24 and Justes (2004) and Brisson et al. (2007) experimented with intercropping barley/pea and
25 they found a reduction in pea yield together with relevant agro-ecological benefits as

1 reductions both of weeds and level of diseases. However, it is hard to understand why the
2 intercropping with rye did not result in yield reduction as is usual in associate cropping
3 systems (Santalla et al. 1994). Other valuable result was the response of the accessions to
4 germinate at sub-optimal temperature. The pea germplasm from the northwest of the
5 Iberian Peninsula averaged 11.0 days to emergence in field in Pontevedra, as reported by
6 Amurrio et al. (1993) and 19.2 days according to a later study by Amurrio et al. (1995).
7 Therefore, the response of the accessions to low temperature during germination, that
8 averaged 27.1 days when the 83.3% of the seeds were successfully germinated, should be
9 considered very good although a further validation under field conditions should be done
10 before to extend the pea crop to cold areas in the North of Spain.

11 The phenotypic selection for agronomic performance within pea landraces applied
12 in this work has resulted in a group of very good field pea breeding lines. The results
13 indicate that field pea could be established as a new protein crop in the North of the Iberian
14 Peninsula to satisfy the demand of plant protein for animal feed. The promotion of this
15 crop should be based more upon adapted breeding lines than commercial unadapted
16 cultivars. Further breeding is needed to release new field pea varieties that combine the
17 adaptation and ability for growing under sustainable conditions with other desirable
18 agronomic traits. Regarding to the cropping system, medium cropping density and
19 monoculture of pea without herbicide application should be a chance for field pea in the
20 farms in Northern Spain maintaining an adequate productivity.

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Table 1. Description for 35 field pea breeding lines and six commercial cultivars.

Lines	Flower colour	Pod shape	Seed shape	Testa colour	Cotyledon colour	Cotyledon shape
MB-0006	white	IV	O	cream	yellow	S
MB-0007	white	IV	O	cream	yellow	S
MB-0009	white	IV	O	cream	yellow	S
MB-0010	white	IV	O	cream	yellow	S
MB-0012	white	IV	S	cream	yellow	S
MB-0013	white	I	G	cream	yellow	SD
MB-0014	white	IV	G	cream	yellow	SD
MB-0015	white	I	S	cream	yellow	S
MB-0024	white	I	O	cream	yellow	S
MB-0026	white	IV	O	cream	yellow	S
MB-0034	white	V	G	brown	yellow	SD
MB-0050	white	I	G	cream	yellow	SD
MB-0052	white	I	G	cream	yellow	SD
MB-0053	purple	I	G	brown	yellow	SD
MB-0098	purple	IV	G	mottled	yellow	SD
MB-0099	purple	IV	G	mottled	yellow	SD
MB-0100	purple	IV	G	mottled	yellow	SD
MB-0102	purple	IV	G	mottled	yellow	SD
MB-0103	purple	I	G	brown	yellow	SD
MB-0107	purple	IV	G	brown	yellow	SD
MB-0109	white	I	S	green	green	SD
MB-0306	purple	IV	G	brown	yellow	SD
MB-0307	white	IV	O	cream	yellow	S
MB-0308	white	IV	S	cream	yellow	S
MB-0309	white	I	S	cream	yellow	S
MB-0310	white	I	S	cream	yellow	S
MB-0311	white	IV	G	brown	yellow	SD
MB-0312	purple	I	O	cream	yellow	S
MB-0313	purple	I	G	brown	yellow	SD
MB-0314	purple	I	G	brown	yellow	SD
MB-0315	white	I	S	cream	yellow	S
MB-0316	purple	IV	G	brown	yellow	SD
MB-0317	purple	I	G	brown	yellow	SD
MB-0318	white	I	G	mottled	yellow	SD
MB-0319	purple	I	G	brown	yellow	SD
ALDERMAN	white	IV	G	green	green	W
ATLAS	white	IV	G	green	green	W
GLOTON	white	I	G	cream	yellow	SD
LOTUS	white	I	G	green	green	W
RONDO	white	IV	G	green	green	W
UTRILLO	white	IV	G	green	green	W

Table 2. Mean squares of the analysis of variance and coefficient of variation for the agronomic traits evaluated in 35 field pea breeding lines and six commercial cultivars.

Source ^a	d.f. ^b	First flower (days)		Flowering (days)		End of flowering (days)		d.f. ^b	First dry pod (days)		d.f. ^b	Seed maturity (days)	
L	1	277222.5	**	325171	**	546975.1	**	1	568290.9	**	1	577299.0	**
R (L)	2	22.5		50.8		22.4		2	1.8		2	8.5	
A	40	514.9	**	259.9	**	386.8	**	40	64.2	**	40	42.8	**
A x L	40	83.6	**	49.5		17.8		40	19.2	*	40	8.4	
Error	80	36.5		35.5		14.5		78	10.8		79	9.7	
C.V. (%) ^c		4.7		4.3		2.1			1.8			1.6	

Source ^a	d.f. ^b	Plant height (cm)		d.f. ^b	Leaflets (nr)		d.f. ^b	Tendrils (nr)		d.f. ^b	Pod length (mm)	
L	1	22894.9	**	1	0.75	*	1	2.19	*	1	1294.3	**
R (L)	2	5333.9	**	2	1.33	**	2	1.15	*	2	419.8	**
A	40	6627.9	**	40	4.21	**	40	10.85	**	40	295.2	**
A x L	40	1072.7	**	40	0.20		39	0.34		39	39.2	*
Error	73	374.3		80	0.17		79	0.33		77	19.4	
C.V. (%) ^c		13.1			8.23			9.14			5.9	

Source ^a	d.f. ^b	Pods plant ⁻¹		d.f. ^b	Seeds pod ⁻¹		d.f. ^b	Seed diameter (mm)		d.f. ^b	Seed weight (g 100 seeds ⁻¹)	
L	1	119276.6	**	1	14.8	**	1	8.44	**	1	147.0	**
R (L)	2	7200.9	*	2	1.1		2	0.98	**	2	2.7	
A	40	5504.2	**	40	1.1	**	40	0.47	**	40	36.3	**
A x L	37	2763.3	**	39	0.9	*	34	0.44	**	29	10.4	**
Error	74	1005.9		77	0.4		54	0.12		42	3.5	
C.V. (%) ^c		44.7			10.8			4.50			9.1	

*, ** significant at $p \leq 0.05$, $p \leq 0.01$ respectively

^a L=Locations, R=Replications, A=Accessions

^b d.f.=degrees of freedom

^c C.V.= Coefficient of Variation

Table 3. Mean comparison and range of variation for the agronomic traits in 35 field pea breeding lines and six commercial cultivars.

Accessions	First flower (days)	Flowering (days)	End of flowering (days)	First dry pod (days)	Seed maturity (days)	Plant height (cm)	Leaflets (nr)	Tendrils (nr)	Pod length (mm)	Pods plant ⁻¹	Seeds pod ⁻¹	Seed diameter (mm)	Seed weight (g 100 seeds ⁻¹)
MB-0006	129	136	177	180	190	135.2	5	5	80.6	41.9	5.8	7.8	22.2
MB-0007	128	137	179	182	192	156.9	5	6	82.6	51.6	5.7	7.4	27.2
MB-0009	124	131	177	181	193	169.1	5	6	82.1	61.3	6.0	7.9	27.6
MB-0010	123	132	179	184	192	145.8	6	6	83.6	39.7	6.3	8.1	27.9
MB-0012	137	144	181	186	194	160.7	6	6	62.6	108.2	6.2	6.9	14.2
MB-0013	138	148	184	190	194	149.4	5	6	67.7	108.8	6.7	7.2	17.4
MB-0014	133	142	183	188	195	187.6	5	5	65.7	134.6	6.1	7.3	17.5
MB-0015	137	147	184	188	194	182.3	5	6	67.2	114.9	7.0	7.8	19.2
MB-0024	130	135	175	185	192	151.9	5	6	75.1	51.8	6.4	7.8	23.6
MB-0026	137	144	181	186	193	166.9	6	7	70.3	71.2	5.3	7.9	23.2
MB-0034	110	126	161	181	188	69.8	4	7	72.6	16.1	5.9	7.9	16.5
MB-0050	110	130	162	178	184	60.7	4	6	64.4	8.30	5.1	8.0	21.7
MB-0052	108	125	166	178	184	55.7	4	7	72.9	7.40	5.5	7.8	20.9
MB-0053	137	142	189	190	196	185.5	5	6	68.5	87.4	5.4	7.9	21.2
MB-0098	129	135	184	186	194	176.1	5	6	81.9	59.9	6.7	8.0	23.9
MB-0099	132	139	184	186	195	170.2	5	6	82.3	63.5	6.6	7.8	24.9
MB-0100	132	139	177	186	193	155.2	4	5	71.6	64.3	6.6	7.9	22.7
MB-0102	131	140	174	186	194	168.9	5	5	73.1	44.5	6.5	8.1	23.7
MB-0103	143	151	182	188	194	161.5	5	6	71.7	53.8	5.6	7.4	18.0
MB-0107	142	152	187	191	195	174.1	5	6	75.8	91.2	6.0	7.5	18.6
MB-0109	109	125	160	154	187	61.8	0	20	59.9	5.70	4.9	7.5	18.1
MB-0306	130	140	180	188	194	161.5	5	6	82.2	86.0	6.7	7.4	22.0
MB-0307	128	138	182	184	194	157.3	6	6	77.2	70.5	6.8	7.4	26.0
MB-0308	125	136	183	186	194	167.0	6	6	74.8	107.0	6.4	7.6	18.5
MB-0309	131	143	187	189	196	195.0	6	6	70.4	146.7	5.4	7.5	24.6
MB-0310	125	141	183	187	195	166.3	5	7	67.4	110.4	5.3	7.7	24.5

Table 3. Continuation

Accessions	First flower (days)	Flowering (days)	End of flowering (days)	First dry pod (days)	Seed maturity (days)	Plant height (cm)	Leaflets (nr)	Tendrils (nr)	Pod length (mm)	Pods plant ⁻¹	Seeds pod ⁻¹	Seed diameter (mm)	Seed weight (g 100 seeds ⁻¹)
MB-0311	127	138	184	187	195	182.7	5	7	77.4	92.5	5.8	7.9	21.1
MB-0312	118	137	187	189	196	147.3	5	6	76.1	75.1	6.0	8.0	28.1
MB-0313	123	141	188	188	195	184.4	6	6	80.0	74.9	6.2	7.6	18.4
MB-0314	134	141	185	188	195	189.4	5	6	67.2	105.6	5.8	7.2	18.5
MB-0315	109	124	175	178	189	162.0	5	6	73.3	111.7	5.5	7.6	18.2
MB-0316	141	159	188	194	196	180.2	5	7	77.9	55.7	6.8	7.8	19.2
MB-0317	139	145	188	188	196	163.6	6	6	61.5	138.9	6.1	7.1	12.0
MB-0318	134	142	187	188	195	160.8	6	6	61.0	121.4	6.6	7.1	13.0
MB-0319	109	113	139	148	159	149.1	6	6	80.1	51.4	6.7	6.4	20.0
ALDERMAN	120	134	156	183	192	112.3	4	6	94.4	3.8	6.3	8.6	26.7
ATLAS	131	139	164	181	188	70.5	6	7	81.7	15.7	6.7	7.9	21.5
GLOTON	114	127	182	184	195	152.5	4	5	72.8	71.7	6.3	7.0	21.8
LOTUS	106	122	161	161	169	54.7	4	5	63.9	13.0	6.4	7.7	15.6
RONDO	122	134	164	182	187	75.9	4	6	93.2	9.28	6.2	8.4	27.5
UTRILLO	115	127	156	181	189	67.4	4	5	95.2	6.02	6.2	8.0	19.3
Mean	126.3	137.1	176.7	183.1	191.3	145.0	4.9	6.3	74.5	67.1	6.1	7.6	21.1
Range of variation	106-143	113-159	139-189	148-194	159-196	57.7-195.0	0-6	5-20	59.9-95.2	3.8-146.7	4.9-7.0	6.9-8.6	12.0-28.1
LSD (0.05) ^a	8.5	8.4	5.4	4.7	4.4	28.2	0.6	0.8	6.3	47.1	0.9	0.5	3.5

^a LSD=Least significant difference at $p<0.05$

Table 4. Mean squares of the analysis of variance and coefficient of variation for the agronomic and seed quality traits evaluated in three field pea breeding lines and one advanced cultivar.

Source ^a	d.f. ^b	First flower (days)		d.f. ^b	End of flowering (days)		First dry pod (days)		Seed maturity (days)		d.f. ^b	Seed yield (g m ⁻²)	
Y	2	244332.00	**	1	62437.51	**	35297.01	**	36528.76	**	2	136072.6	**
L	1	5625.00	**	1	228.76	**	310.64	**	4641.01	**	1	254443.7	**
Y x L	1	517.56	**	1	1670.76	**	319.51	**	123.76	**	2	92995.8	**
R (Y x L)	5	26.04	**	4	2.73		3.67		486.26	**	6	22742.1	**
D	1	19.02		1	0.76		4.51		0.76		1	9338.6	
D x Y	2	5.13		1	2.64		0.14		0.01		2	21561.3	*
D x L	1	0.25		1	0.01		1.26		0.76		1	7014.1	
D x Y x L	1	0.56		1	3.51		0.76		0.01		2	15446.6	*
A	3	67.43	**	3	11.14		7.64	*	5.97		3	10519.3	
A x Y	6	62.21	**	3	20.60		2.81		5.56		6	2681.7	
A x L	3	14.29		3	2.60		0.76		5.97		3	5671.6	
A x Y x L	3	6.69		3	1.43		1.56		5.56		6	8200.0	
A x D	3	1.71		3	7.26		1.81		8.64		3	4422.5	
A x Y x D	6	6.12		3	7.47		4.68		5.39		6	3115.1	
A x L x D	3	2.79		3	1.43		3.81		8.64		3	9345.2	
A x Y x L x D	3	4.60		3	1.26		1.56		5.39		6	2516.3	
Error	30	5.29		24	3.25		2.45		4.87		35	4518.4	
C.V. (%) ^c		2.06			1.05		0.93		1.10			34.0	

Table 4. Continuation

Source ^a	d.f. ^b	Protein content (g kg ⁻¹)	Fibre content (g kg ⁻¹)	Starch content (g kg ⁻¹)
Y	1	819.5 **	18.56	1478.5 **
L	1	633.9 **	369.94 **	2325.3 **
Y x L	1	7812.3 **	16.70	5312.7 **
R (Y x L)	4	256.1 **	19.89	241.5
D	1	486.7 **	68.00	1137.4 **
D x Y	1	352.2 *	0.13	425.1
D x L	1	50.9	21.33	115.6
D x Y x L	1	227.0 *	115.96 *	433.4
A	3	757.5 **	258.01 **	1339.8 **
A x Y	3	86.8	77.25 *	734.7 **
A x L	3	42.0	70.20 *	95.7
A x Y x L	3	3.9	26.13	94.2
A x D	3	39.1	32.28	78.6
A x Y x D	3	41.6	72.88 *	99.8
A x L x D	3	4.7	76.69 *	112.6
A x Y x L x D	3	84.1	15.11	309.2
Error	24	46.3	19.07	105.2
C.V. (%) ^c		2.65	5.77	2.06

*, ** significant at $p \leq 0.05$, $p \leq 0.01$ respectively

^a Y=Years, L=Locations, R=Replications, D=Cropping density, A=Accessions

^b d.f.=degrees of freedom

^c C.V.= Coefficient of Variation.

Table 5. Mean and range of variation for the agronomic and seed quality traits evaluated in three field pea breeding lines and one advanced cultivar

Accession	First flower (days)	End of flowering (days)	First dry pod (days)	Seed maturity (days)	Seed yield (g m ⁻²)	Protein content (g kg ⁻¹)	Fiber content (g kg ⁻¹)	Starch content (g kg ⁻¹)
PMB-0307	110	172	169	201	187	260	71	496
PMB-0308	112	173	169	199	221	258	73	498
PMB-0319	113	173	170	200	177	261	79	488
ZP-1233	110	171	169	200	205	246	79	511
Mean	112	172	169	200	197	256	76	498
Range of variation	58.0-156.0	129.0-208.0	139.0-196.0	160.0-236.0	177.1-221.2	225.0-297.0	60.1-89.3	442.0-533.0
LSD (0.05) ^a	1.48		1.14			4.9	3.2	7.5

^a LSD= Least significant difference at $p < 0.05$

Table 6. Mean squares of the analysis of variance and coefficient of variation for the agronomic performance traits evaluated under different field treatments in three field pea breeding lines and one advanced cultivar.

Source ^a	d.f. ^b	Pods plant ⁻¹	Seeds pod ⁻¹	Seed weight (g 100 seeds ⁻¹)	Seed yield (g m ⁻²)
T	3	0.87	0.10	7.28 **	5390.2
R	1	0.60	0.04	0.57	1730.9
A	2	1.46	0.70 *	7.53 **	5164.5
A x T	6	1.82	0.22	2.30 *	1328.8
Error	11	2.23	0.11	0.62	3755.1
C.V. (%) ^c		16.65	8.34	3.32	21.9

*, ** significant at $p \leq 0.05$, $p \leq 0.01$ respectively

^a T=Treatments: check, intercropped with rye, with pre-emergence herbicide, with post-emergence herbicide, R=Replications, A=Accessions

^b d.f.=degrees of freedom

^c C.V.= Coefficient of Variation.

Table 7. Mean and range of variation for the agronomic performance traits evaluated under different field treatments in three field pea breeding lines and one advanced cultivar.

	Pods plant ⁻¹	Seeds pod ⁻¹	Seed weight (g 100 seeds ⁻¹)	Seed yield (g m ⁻²)
Accession				
PMB-0307	9.1	4.1	24.1	297.1
PMB-0308	9.3	4.3	22.7	294.0
PMB-0319	8.5	3.7	24.6	251.6
Mean	9.0	4.0	23.8	280.9
Range of variation	8.5-9.3	3.7-4.3	22.7-24.6	251.6-297.1
LSD (0.05) ^a		0.4	0.9	
Treatment^b				
A	9.5	4.0	23.2	301.1
B	8.7	4.2	25.4	237.9
C	9.1	4.0	23.4	301.7
D	8.7	4.0	23.1	283.0
Mean	9.0	4.0	23.8	280.9
Range of variation	8.7-9.5	4.0-4.2	23.1-25.4	237.9-301.7
LSD (0.05) ^a			0.9	

^a LSD=Least significant difference at $p<0.05$

^b A: control, B: intercropped with rye, C: with pre-emergence herbicide, D: with post-emergence herbicide