Food and feed potential breeding value of green, dry and vegetable pea germplasm

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Santalla, M., Amurrio, J. M. and De Ron, A. M. 2001. **Food and feed potential breeding value of green, dry and vegetable pea germplasm.** Can. J. Plant Sci. **81**: 601–610. Pea is an important grain legume and vegetable in the South of Europe where it is grown on small farms and gardens using traditional varieties and methods during the winter. Variability in old, unimproved varieties needs to be determined in order to create useful genetic variation for broadening the narrow genetic base of commercial cultivars and for making efficient use of available resources. One hundred and four unimproved pea varieties and ten elite cultivars were evaluated in 1991 and 1992 at two locations for seed and vegetable quality, canopy and agronomic traits. Significant genotype by environment (G × E) interactions were found for protein concentration, fresh seed size and weight, canopy traits, pod length and weight, days to flowering, and days to fresh seed and pod maturity. There were significant differences between unimproved pea varieties for all traits studied except for seed soluble sugars and seed tenderness. Most of the significant differences for seed and vegetable quality traits were observed in the unimproved germplasm from the South of Europe when compared with differences within the elite germplasm. Data from the evaluation of available pea germplasm provide information needed by breeders to develop varieties efficiently for the different needs of growers, processors and feed manufacturers. The relevance of these results in devising breeding strategies is discussed.

Key words: *Pisum sativum*, seed and vegetable quality, field performance, genotype by environment interaction

Santalla, M., Amurrio, J. M. et De Ron, A. M. 2001. **Potentiel fourrager et vivrier du matériel génétique du pois sec et frais**. Can. J. Plant Sci. **81**: 601–610. Le pois est abondamment utilisé comme légumineuse à graine dans le monde et comme légume dans le sud de l'Europe, où on en cultive des variétés traditionnelles en hiver, dans les fermettes et les potagers, selon des méthodes classiques. Il est capital de préciser la composition génétique des anciennes variétés non améliorées si l'on veut engendrer des variations qui élargiront la base génétique limitée des cultivars commerciaux et garantir une exploitation efficace des ressources existantes. Cent quatre variétés non améliorées de pois et dix cultivars élite ont fait l'objet d'évaluations à deux endroits en 1991 et 1992. Ont été évalués la qualité grainière et légumière, le feuillage et les paramètres agronomiques. La concentration de protéines, la taille et le poids des graines fraîches, les caractéristiques du feuillage, la longueur et le poids des gousses, le nombre de jours avant la floraison et le nombre de jours avant la maturité de la gousse et la graine verte révèlent une importante interaction du génotype avec l'environnement. Les caractères varient de façon significative chez les variétés non améliorées, à l'exception de la concentration de sucres solubles dans la graine et de la tendreté de cette dernière. La plupart des grandes variations qui affectent les paramètres de la qualité grainière et légumière surviennent dans le matériel génétique des variétés non améliorées du sud de l'Europe, et non chez les variétés élite. Les données issues de l'évaluation du matériel génétique disponible aideront les obtenteurs à créer des cultivars qui répondront aux exigences des producteurs, des transformateurs et des fabricants de provende. Suit une discussion sur la pertinence des résultats pour l'élaboration de stratégies d'hybridation.

Mots clés: *Pisum sativum*, qualité grainière et légumière, rendement au champ, interaction du génotype et de l'environnement

Pea (*Pisum sativum* L.) is a traditional and important edible crop grown by farmers in the South of Europe during the cool season. For centuries the crop has been an important raw material for feed and food purposes in many forms including forage for animal feeding, fresh seeds for canning and freezing, dry seeds, partly for human consumption, but mostly for animal feeding, and pods as a fresh vegetable for human consumption (Cousin 1997).

Dry pea is a widely consumed grain legume in developing countries, where, for economic or socio-ecological reasons, it is an important source of dietary protein. By contrast, in developed countries, there has been a decline in dry pulses in the human diet. The consumption trend is toward animal sources of protein and the substitution of dry pulses by fresh seeds (vining peas), or fresh pods (sugar peas), which deserve increasing interest because they are consumed as French beans (Kay 1979; Amurrio et al. 1996). For consumers and industrialists, pea, as a European vegetable protein source, has a favourable image with additional value in terms of environment, reducing fertiliser use in agriculture, and food safety (Bovine Spongiform Encephalopathy disease). It is a safe raw material with no specific problems of mycotoxin, pesticide or fungicide residues (Bourdillon 1998), and with good nutritional and economic value. Also, the rapid increase of meat consumption in the world has pro-

Abbreviations: **G × E**, genotype by environment duced a huge demand for protein-rich feedstuffs (FAO 1996; Bernicot et al. 1998). Europe has long been deficient in protein-rich feedstuffs for livestock feeding and has relied heavily on soybean meal, along with a few other oilseed meal imports. Hence, the European Union encouraged the use and development of local pea crops to improve self-sufficiency in protein-rich feedstuffs, in order to limit dependency on imports. Peas have also become popular in human foods thanks to their hypocholesterolaemic properties. Many people are concerned by coronary heart diseases (accounting for more than 40% of deaths occurring in developed countries), due in part to the over-consumption of saturated lipid diets, and choose diets low in fat or diets allowing the control of blood cholesterol. However, European pea production did not increase at a sufficient rate, resulting in a new demand for imported pea.

Considerable breeding efforts have been made with pea over the past decade to develop high-yielding varieties. Different strategies were developed according to the agronomic and economic optimum specific for each country (Slinkard and Murray 1979; Pyke and Hedley 1983; Dumoulin et al. 1996). Breeding varieties for high yield has been the main objective in France, whereas standing ability to overcome harvesting difficulties has been the main priority for northern European countries, including the United Kingdom. Nowadays, consumers are becoming better educated about nutrition, and more sophisticated in choosing foods that are wholesome and nutritious, and the food industry is reacting to their desire to eat more “natural” and healthy foods. The market for deep-frozen or canned food is growing fast and producers need specialised ingredients that meet strict technological and nutritional criteria. Pea products immediately found a gap in the market, thanks to original properties, and the potential for development is high. Breeding additional pea varieties with tender edible pods and without a parchment layer could be a good strategy for finding a new vegetable and to increase the range of uses of pea for food manufacturers and consumers.

Currently, Spain and Germany are the biggest importers of pea, mainly from Canada, while France and Canada are the largest exporting countries (FAO 1996). France, with the highest amount of pea incorporated into animal diets, is the main European user. Outside France, the major European pea-consuming countries are Spain and Germany for animal feeding and United Kingdom for human consumption (fresh seeds and pods). Pea production in Europe is unstable, especially in Spain where yield is low and averages of 600 and 6311 kg ha^{-1} of dry and fresh seeded pea, respectively, are obtained (FAO 1997).

In Spain, pea is a popular crop and is always present in small farms and gardens. Farmers use their own seeds year after year with occasional exchange of seed with the surrounding fields. The socioeconomical peculiarities of this area, the use of unimproved varieties grown in smallholdings and the use of the same seed supply have resulted in the maintenance of a high degree of genetic diversity. Unimproved pea varieties show differences in canopy, time to maturity, pod size and type, and seed attributes. These old, unimproved varieties are furthermore highly adapted to the specific environmental conditions of this area and are an important source of genetic variation (Zeven 1998). Old varieties and garden forms, both unimproved, have been collected by the Mision Biologica de Galicia since 1987 (Ron et al. 1991). Investigation of the genetic potential of the pea varieties grown in this area is important as a means of improving crop management techniques, including choice of variety for the different purposes, making the pea crop as competitive as possible with other important European crops.

The purpose of this investigation was: 1) to evaluate the available unimproved germplasm diversity in quality, canopy and agronomic traits over a wide range of multi-environmental tests (MET) conditions; and 2) to compare the unimproved germplasm with that of elite pea cultivars usually grown by farmers. This genetic study illustrates the degree and origin (genetic or environment) of the variability of these traits, and predicts the potential of this germplasm as a source of basic genetic material for pea breeding programs.

MATERIALS AND METHODS

The study included 104 unimproved pea varieties and garden forms representative of the material currently cultivated in Spain, and 10 elite cultivars for different uses (Table 1). These accessions can be considered as unimproved populations because they have been maintained as a mixture of pure lines by farmers for generations.

Field experiments were conducted during the European cool seasons of 1991–1992 and 1992–1993 at the Mision Biologica de Galicia in Salcedo-Spain (42°24′N latitude 81°38′W longitude, 40 m altitude, 14°C average temperature, average annual rainfall 1608 mm) and Lalin-Spain (42°38′N latitude 8°10′W longitude, 600 m altitude, 11°C average temperature, average annual rainfall 1099 mm). Diseases and pests were controlled as needed in all trials. The experimental design was a randomized complete block with two replications per trial. Each experimental plot consisted of a single 3.5-m row, with row spacing of 80 cm and plant spacing of 25 cm. Seed was hand-sown, but over planted by 100% and thinned to 15 plants per plot after emergence.

The seed quality traits evaluated were: proportion of abortions, fresh size (the average diameter of 10 fresh seeds), fresh weight (the average of 50 fresh seeds), tenderness (the average of 10 fresh seeds by a penetrometer), and total soluble sugars (measured by a hand sugar refractometer). Dry seed protein concentration was determined by Near Infrared Transmittance, which has become an appropriate method for food and feed analysis in plant breeding programmes (Williams et al. 1978; Rudzik 1990), because it is a rapid and non-destructive technique.

Canopy data were recorded when the plants reached maximum vegetative development of the main stem. The following traits were determined on five randomly chosen plants and included: internode length (measured above to node of the first flower), length of the main stem to the first flower, the number of basal branches (those originated from the lowest basal bracts and lowest stem nodes), and the number of nodes to the first flower. Number of tendrils and leaflets and length and width of leaflet and stipule were recorded on five normal leaves per plot.

Table 1. Unimproved varieties and elite cultivars of pea and their phenotypic characteristics

Unimproved variety[z] Elite cultivar[y]	Phenotypic characteristics						
	Group	Flower colour	Cotyledon coat color	Cotyledon coat shape	Parchment layer[x]	Pods per node	Leaflet shape
37, 39, 72[w], 101, Atlas, Rondo Quantum, Tristar, Utrillo	1	Purple, white	Green, yellow, brown	Smooth, wrinkled, smooth with dimples	0	1/2/3	Round, narrow oval
13, 16, 17[w], 24, 38, 53[w], 61[w], 75, 89, 90, 95, 102[w], 103, 107[w] 134, Lotus, Ballet, Progress	2	Purple, white	Green, yellow, brown	Smooth, wrinkled, smooth with dimples	0/1	1/2	Round, narrow oval
10[w], 88[w], 165[w], 171[w], 173[w], 195[w]	3	Purple, white	Green , yellow and brown	Smooth	1	1/2/3	Narrow oval
11[w], 14, 18, 19, 23, 25, 27, 28, 40, 44[w], 47, 50, 55, 57, 59, 62, 76, 79, 81, 92, 94, 96[w], 99, 106, 108, 119, 120, 127, 128, 132, 137, 143, 144, 146, 147, 153[w], 163[w]	4	Purple, white	Green , yellow, brown	Smooth, wrinkled, smooth with dimples	0/1	1/2	Narrow oval, lanceolate
176, 203	5	White	Green, yellow, brown	Smooth, smooth with dimples	1	1/2	Absent, round oval
68, 83, 84[w], 85[w], 86, 87, 148, 150, 151[w], 152[w], 164[w], 172[w], 175[w], 177, 178, 179, 180[w], 189, 202, Belinda	6	Purple, white	Green, yellow, brown	Smooth, wrinkled, smooth with dimples	1	1/2	Narrow oval, lanceolate
22, 66[w], 110[w], 111, 112, 113, 114[w], 115, 116, 118, 121, 122, 123, 124, 125, 191, Capuchino	7	Purple, white	Green, yellow, brown	Smooth, wrinkled, smooth with dimples	0/1	1/2	Narrow, round oval
60[w], 117[w], 135	8	Purple, white	Green, yellow, brown	Wrinkled, smooth with dimples	0/1	1/2	Narrow oval
70[w]	9	Purple, white	Brown	Smooth, wrinkled	0/1	1	Round oval
64	10	Purple	Brown	Wrinkled	0	2	Round oval

[z]Accessions in the MBG-CSIC (Mision Biologica de Galicia-Consejo Superior de Investigaciones Científicas) germplasm collection are identified by PSM (*Pisum sativum*-MBG) plus a number.
[y]Elite cultivars for greed seed consumption: Tristar, Lotus, Quantum, Rondo, Utrillo, Progress and Atlas; for dry seed consumption: Ballet and Belinda; and for vegetable consumption: Capuchino.
[x]1 and 0 = presence and absence of the parchment layer in the unripe pod, respectively.
[w]Mixture of pure lines.

The vegetable quality traits evaluated were: length (measured from the pod apex to the tip of the pod) and width (distance at right angles to the sutures), expressed as the mean of a sample of five pods, and fresh weight (determined on five pods when they reached the optimal maturity stage for fresh consumption, i.e., when they have the minimum fibre content).

The agronomic traits were measured on the whole plot and were: number of pods per plant, number of seeds per pod, pod and seed yield per plant, days to flowering (number of days from sowing until 50% of plants per plot had at least one open flower), days to fresh pod maturity (number of days from sowing until 50% of plants per plot had green pods for fresh consumption), and days to fresh seed maturity (number of days from sowing until 50% of plants per plot had green seeds for fresh consumption).

In order to obtain complete information and a better description of unimproved pea varieties, the following qualitative traits were also considered in the evaluation: flower colour (purple or white), number of pods per reproductive node (evaluated on the first and second pod-bearing node), fresh pod apex and shape, presence or absence of the parchment layer, dry seed coat colour (yellow, green or brown), dry seed coat shape (smooth, wrinkled or smooth with dimples) and dry seed hilum colour. The qualitative traits were transformed by special coding (Romesburg 1984; Vanderborght and Depiereux 1987) and the unimproved varieties were grouped by numerical procedures (Unweighted Pair-Group Method using arithmetic averages or UPGMA) using the NTSYS program.

Individual and combined analyses of variance across environments for all traits studied were performed. Locations, years and unimproved varieties were considered random effects. All data analyses were performed using the SAS program (SAS Institute, Inc. 1990). Because some data were missing from the field trials, combined analysis of variance were performed according to: 1) four environments: two seasons (1991–1992 and 1992–1993) and two locations (Salcedo and Lalin), 2) three environments: two seasons (1991–1992 and 1992–1993) and one location (Salcedo), and one season (1992–1993) and one location (Lalin), and 3) two environments: one season (1991–1992) and two locations (Salcedo and Lalin). All experiments had two replications. Means, standard errors, ranges and coefficients of variation were determined for all traits studied.

RESULTS AND DISCUSSION

The 104 unimproved pea varieties plus 10 elite cultivars were clustered in 10 groups according to the qualitative traits studied. Table 1 shows the different states of the most important qualitative traits for each group. The pattern of variation showed that some of the unimproved pea varieties are in fact a mixture of pure lines, which are maintained by farmers, perhaps including some improved or commercial material. This intra-unimproved variety variation allows individual selection as a means to improve some unimproved varieties. This is a base-step in breeding programs focussed on obtaining new cultivars (Kelly et al. 1999). Pure lines identified from single plants with desirable characteristics could be used for increased genetic diversity. Variation within unimproved varieties was mainly observed for qualitative traits, while for quantitative traits substantially less variation within unimproved varieties was detected. Elite cultivars are, furthermore, considered to be pure lines, derived from single plant selection, and no phenotypic intra-cultivar variation has been observed.

Analyses of variance for seed quality traits are shown in Tables 2 and 3. Significant genotypic differences were observed for most of the traits determined except for soluble sugars and tenderness, although the significant differences were only detected in the unimproved germplasm. The combined analysis of pea varieties over environments showed significant G $\times$ E interaction for protein concentration. Significant environment differences were observed for protein concentration and fresh size. The elite group had significantly higher values for fresh size and weight compared with the unimproved group. Recently, the main breeding objectives in vining (green) and dry pea varieties have been to select plants with large seed size and weight. However, in Europe there are different quality requirements according to each different use and a common classification and nomenclature was proposed (Carrouée 2000). Thus, dry pea production for pig and poultry feed is of smooth-seeded varieties, which are pale yellow or pale green, with white flowers, and large seeds, whereas ruminant and pigeon feed is based on smooth, dimple-seeded varieties, brown in colour and with large seeds. On other hand, green pea production for human food is focussed on smooth, smooth with dimples and wrinkle-seeded pea varieties, and large seed size. However, small-seeded pea varieties also deserve attention by European consumers, and they are popular named “petis pois”. These pea varieties also have economic importance due to the fact that the consumers relate small size to tenderness.

The rapid increase of meat consumption in the world and the production of cheap and low-fat meat requires a high content of protein feedstuffs. In this study, unimproved pea varieties had seed protein concentration similar to, and not significantly different from the elite cultivars. Previous research (Cousin et al. 1992) demonstrated that both genetic and environmental effects are significant in this trait and wrinkle-seeded pea varieties had higher protein concentration than smooth-seeded pea varieties. Some unimproved pea varieties studied were variable for cotyledon shape. In fact, they are a mixture of pure lines, which could have caused a decrease in the determination of the protein concentration. This is interesting because these unimproved varieties could be subjected to individual selection, and the protein concentration could be increased.

Elite cultivars for green and dry seed consumption are clustered in groups 1, 2 and 6. These groups include unimproved varieties with different phenotypic characteristics and with appropriate seed quality characteristics (Table 10). Thus, group 1 included unimproved pea varieties with the largest seed weight, while groups 2 and 6, and also group 3, included some unimproved varieties that have good characteristics for the commercial market class “petis pois” because they have the smallest seed size. Besides, these

Table 2. Mean squares of the combined analyses of variance over three environments, mean, standard error, coefficient (CV) and range of variation for seed quality traits in the pea unimproved varieties studied

Source of variation	Seed quality traits: Protein concentration (%)
Environments	224.81**
Replications (E)[z]	0.06
Varieties	2.44**
Unimproved	2.49**
Elite	1.79
U-C[z]	2.89
Varieties × E	1.60**
U × E	1.62**
C × E	0.87
U-C × E	7.71
Error[y]	1.06
CV (%)	4.62
Mean	
Unimproved	22.50 ± 0.423
Elite	22.27 ± 0.247
Range of variation	
Unimproved	20.97 – 24.70
Elite	20.30 – 24.23

[z]E = environments, U = unimproved varieties and C = elite cultivars.
[y]Degrees of freedom for the error due to missing data: protein concentration = 235.

Table 3. Mean squares of the combined analyses of variance over two seasons and 2 yr, mean, standard error, coefficient (CV) and range of variation for seed quality traits in the pea unimproved varieties studied

Source of variation	Seed quality traits: Soluble sugars (%)	Tenderness (mm)	Fresh Size (mm)	Fresh weight (g)
Seasons	1209.46	2.59	309.80*	702.13
Locations	23.20	241.32	28.45	1022.15
S × Locations[z]	180.28**	0.00	1.28	221.77
Replications (S × L)[z]	1.85	304.80**	5.03**	66.71**
Varieties	18.05	24.64	4.78**	127.52**
Unimproved	18.21	21.92	4.77**	121.92**
Elite	13.50	58.17	3.55	110.88
U-C[z]	42.66	5.79	16.78**	859.58**
Varieties × S	5.00	19.90	0.61	13.29
U × S	4.26	21.26	0.59	13.46
C × S	14.02	6.62	0.77	12.24
U-C × S	0.78	0.00	1.29	5.21
Varieties × L	0.84	18.35	0.63	19.20
U × L	7.10	18.40	0.64	15.85
C × L	14.16	15.17	0.57	43.48
U-C × L	28.21	42.14	0.27	148.24
Varieties × S × L	12.04**	21.98*	0.53	16.17
U × S × L	12.13**	21.88*	0.55	15.24
C × S × L	8.01	21.49	0.43	28.03
U-C × S × L	30.63	35.12	0.00	28.05
Error[y]	5.90	16.02	0.58	15.38
CV (%)	20.67	31.14	8.45	19.47
Mean				
Unimproved	11.7 ± 0.86	12.8 ± 1.43	8.96 ± 0.268	19.5 ± 1.33
Elite	12.6 ± 0.81	13.6 ± 1.19	9.49 ± 0.277	23.5 ± 1.98
Range of variation				
Unimproved	8.7–15.1	8.3–17.3	7.17–10.52	10.2–30.2
Elite	9.4–14.8	9.3–17.4	8.48–11.09	18.0–31.4

[z]S = seasons, L = locations, U = unimproved varieties and C = elite cultivars.
[y]Degrees of freedom for the error due to missing data: soluble sugars = 414, tenderness = 436, fresh size = 439, and fresh weight = 439.

small values of seed size are not found through the elite germplasm group (Table 3). These groups included unimproved varieties that are classified on the seed characteristic smooth, wrinkled and smooth with dimples. Wrinkled unimproved pea varieties from groups 1, 2 and 6 could be used only to select frozen pea cultivars. Some other types of unimproved varieties, such as smooth peas with dimples, and brown colour, have and economic impact in some countries with a premium for specific outlets (canning and pigeon feed). These pea cultivars are defined by visible characteristics and by the point of view of the users, but not by clear and specific characteristics of composition. For instance, unimproved varieties with smooth seeds, and yellow and green colour, specially unimproved varieties included in group 3, and in consequence with low tannin content are the only, but rather long way to describe the most widely produced pea cultivars in the European Union for monogastric nutrition. They are called by a short name "feed peas".

Significant genotypic differences were observed for all the canopy traits studied (Tables 4 and 5). No significant differences were found between environments for leaflet and stipule dimensions, and number of tendrils and leaflets. A significant G × E interaction was detected for all the canopy traits determined. The absence of a significant G × E interaction in the elite group for most of the canopy traits evaluated is striking and confirms that this germplasm has been subjected to selection pressure. However, the existence of a significant interaction for node of first flower in both types of germplasm has a practical importance because this trait and flowering date are usually used to predict the harvest date (Gritton 1969). Bourion et al. (1998) found the number of the first flowering node seems to be an adequate indicator of flowering earliness. A G × E interaction for both traits was also detected by Snoad and Arthur (1974) and Kaul and Garg (1982).

The elite group showed significantly shorter internodes, lengths of the stem to the first flower and of node of first flower, lower number of basal branches, smaller leaflets and stipules, and higher numbers of tendrils compared with the unimproved group. Over the past few decades, breeders aimed to increase standing ability, which could reduce disease development and harvesting losses and increase yield potential and adaptability for harvest. Walton (1990) found that reduction in leaf area to produce smaller and more highly branched plants would favour yield, and Cousin et al. (1985) found in a multiple regression analysis in a range of traits that leaf area, plant height and number of seeds per pod were negatively correlated with yield. Hence, one of the primary objectives was the assessment of radically altered phenotypes, which have reduced biomass due to the absence of true leaflets (semileafless trait) or the characteristic large stipules or both, and shortened internodes, which permitted the development of the currently elite cultivars.

Unimproved varieties with shortened internode length and length to first flower are included in groups 1, 2 and 4, while, unimproved varieties with reduced leaf area and with a large number of tendrils are grouped in group 5 (Table 10). The unimproved varieties with the shortened node count to the first flower are included in groups 1 and 5. Collins and

Table 4. Mean squares of the combined analyses of variance over two environments, mean, standard error, coefficient (CV) and range of variation for canopy traits in the pea unimproved varieties studied

Source of variation	Canopy traits						
	Internode length (cm)	Length to first flower (cm)	No. of basal branches	Leaflet length (cm)	Leaflet width (cm)	Stipule length (cm)	Stipule width (cm)
Environments	610.54**	375920.0**	20.79*	0.13	0.30	4.12	9.08
Replications (E)[z]	10.79*	814.4	1.25*	1.20	0.90	2.77	1.94*
Varieties	16.95**	8291.9**	4.16**	3.16**	1.50**	4.86**	2.03**
Unimproved	11.97**	6933.0**	3.96**	2.15**	1.14**	3.76**	1.67**
Elite	14.05	2300.9	0.40	6.92**	3.20**	4.56	2.83**
U-C[z]	561.02**	203534.9**	57.97**	74.75**	24.41*	121.28**	32.65**
Varieties × E	4.72**	1649.9**	0.64**	0.67**	0.45**	1.51**	0.61*
U × E	4.65**	1550.0**	0.67**	0.65**	0.46*	1.44**	0.62*
C × E	4.94**	796.5**	0.36	0.78	0.19	1.78	0.26
U-C × E	10.20**	19720.1*	0.72	1.73	1.66	5.89	2.07
Error[y]	2.68	809.2	0.46	0.46	0.32	1.01	0.44
CV (%)	18.24	21.57	26.67	14.27	20.49	12.33	14.60
Mean							
Unimproved	9.3 ± 0.84	138 ± 14.7	2.63 ± 0.284	4.88 ± 0.330	2.85 ± 0.292	8.29 ± 0.485	4.62 ± 0.267
Elite	5.2 ± 0.39	60 ± 6.1	1.57 ± 0.188	3.37 ± 0.437	1.98 ± 0.180	6.30 ± 0.692	3.61 ± 0.390
Range of variation							
Unimproved	4.7 – 13.3	53 – 233	1.10 – 5.43	0.00 – 6.31	0.00 – 4.37	5.61 – 10.44	3.11 – 6.30
Elite	3.5 – 8.9	30 – 114	1.26 – 1.98	0.00 – 4.69	0.00 – 3.02	4.52 – 7.87	2.24 – 5.13

[z]E = environments, U = unimproved varieties and C = elite cultivars.
[y]Degrees of freedom for the error due to missing data: internode length = 221, length to first flower = 217, number of basal branches = 337, leaflet length and width = 220 and stipule length and width = 220.

Table 5. Mean squares of the combined analyses of variance over two seasons and 2 yr, mean, standard error, coefficient (CV) and range of variation for canopy traits in the pea unimproved varieties studied

Source of variation	Canopy traits		
	No. tendrils	No. leaflets	Node of first flower (cm)
Seasons	168.08	85.84	29.75
Locations	24.27	133.89	1512.50**
S × Locations[z]	65.27**	58.16**	10.77
Replications (S × L)[z]	0.95	4.05*	4.64
Varieties	3.77**	4.36**	42.00**
Unimproved	2.14**	3.02**	34.69**
Elite	19.03**	17.97**	52.79**
U-C[z]	35.98**	21.53**	705.50**
Varieties × S	0.98**	0.60**	4.76*
U × S	0.86	0.58*	5.00*
C × S	0.92**	0.89	2.43*
U-C × S	14.44**	0.88	0.74
Varieties × L	0.70	0.57*	18.87**
U × L	0.72	0.47	19.32**
C × L	0.14	0.60	4.38**
U-C × L	3.05	10.44*	102.76**
Varieties × S × L	0.60**	0.39*	3.12*
U × S × L	0.64**	0.39**	3.29
C × S × L	0.10	0.34	0.77
U-C × S × L	0.11	0.46	2.04
Error[y]	0.42	0.29	2.25
CV (%)	11.21	11.77	10.60
Mean			
Unimproved	5.75 ± 0.232	4.62 ± 0.185	14.43 ± 0.545
Elite	6.44 ± 0.235	4.05 ± 0.233	11.31 ± 0.487
Range of variation			
Unimproved	4.73 – 9.31	0.00 – 5.73	9.45 – 20.55
Elite	5.19 – 10.63	0.00 – 5.48	6.27 – 16.13

[z]S = seasons, L = locations, U = unimproved varieties and C = elite cultivars.
[y]Degrees of freedom for the error due to missing data: number of tendrils = 451, number of leaflets = 452 and number of node to first flower = 448.

Wilson (1974) concluded that the trait node of the first flower is useful as an index of development and it can be used to estimate the time of initiation of the first flower. Thus, the early-flowering unimproved pea varieties would be found in groups 1 and 5.

Significant genotypic differences for all vegetable quality traits studied are shown in Table 6. Non-significant G × E interactions were observed for proportion of abortions, fresh weight and width. The longest and widest pods were found in the elite germplasm group. Recently, the production of an edible-podded pea variety with thick walls has aroused a great deal of interest among consumers and may offer some possibilities for expanded commercial production and use. These “sugar pea” cultivars must fulfill the pod quality requirements of long and wide, fleshy pods, and they must have no parchment layer in the unripe pod. This last condition is found only in pea varieties with the *ppvv* genetic constitution (Makasheva 1983).

The unimproved pea varieties with the most appropriate pod characteristics for human consumption are included in groups 7, 9 and 10. Some unimproved varieties from these groups did not present a parchment layer in the unripe pod, although some of them are a mixture of pure lines, and could be grown as “sugar pea” varieties. Some unimproved varieties in groups 2, 4 and 8 did not show large pods, but they deserve attention because they have no parchment layer in the unripe pod. Capuchino is the only “sugar pea” cultivar cultivated and consumed in Spain that is included in group 8. These varieties usually have purple flowers, but white types are also grown.

Significant genotypic differences were observed for all the agronomic traits (Tables 7, 8 and 9) and a G × E interaction was found for days to flowering, days to fresh seed

Table 6. Mean squares of the combined analyses of variance over two seasons and 2 yr, mean, standard error, coefficient (CV) and range of variation for vegetable traits in the pea unimproved varieties studied

	Vegetable quality traits			
Source of variation	Abortions (%)	Fresh pod weight (g)	Length (mm)	Width (mm)
Seasons	38118.4	8.62	5336.6	71.34
Locations	3937.5	31.58**	4696.6	74.78
S × Locations[z]	565.6**	0.11	157.0	19.90
Replications (S × L)[z]	297.1**	1.96**	357.7**	7.44
Varieties	546.5**	5.55**	1147.2**	42.29**
Unimproved	558.5**	4.91**	1102.4**	41.47**
Elite	455.8	8.89	1487.0*	48.68**
U-C[z]	116.4*	42.10*	2756.0*	70.16*
Varieties × S	146.6	0.51	87.2*	3.91
U × S	127.7	0.45	86.8*	3.83
C × S	335.0*	1.23	94.0	4.73
U-C × S	409.8**	0.79	67.2	4.13
Varieties × L	86.7	0.64	94.4*	3.82
U × L	80.8	0.42	72.7	3.56
C × L	137.5	2.64	265.1	6.65*
U-C × L	245.0**	6.26	810.5	5.97
Varieties × S × L	124.8**	0.51*	61.4**	4.10
U × S × L	120.5**	0.47*	56.8*	4.35
C × S × L	86.0	1.05	130.2*	1.45
U-C × S × L	841.7**	0.22	0.0	0.27
Error[y]	80.1	0.40	43.2	3.39
CV (%)	32.99	29.13	9.07	11.68
Mean				
Unimproved	27.1 ± 3.11	2.09 ± 0.211	71.9 ± 2.30	15.7 ± 0.67
Elite	27.5 ± 3.91	2.96 ± 0.293	78.8 ± 2.31	16.8 ± 0.36
Range of variation				
Unimproved	8.3 – 48.4	0.71 – 4.88	48.8 – 105.1	10.7 – 21.8
Elite	17.8 – 37.9	1.92 – 5.52	65.9 – 114.4	13.9 – 22.3

[z]S = seasons, L = locations, U = unimproved varieties and C = elite cultivars.
[y]Degrees of freedom for the error due to missing data: proportion of abortions = 436, fresh weight = 428, and length and width = 433.

maturity and days to fresh pod maturity, although yield and pods per plant were evaluated only across one environment. Pods per plant, seeds per pod and yield had significantly superior scores in the unimproved germplasm group compared with the elite group. Validation of some of these results would require evaluation across different environments and under ordinary commercial cultural conditions, where the competition among plants is much more severe. The earliest flowering and maturing pea varieties are found in groups 1, 2, 4 and 5, while the highest-yielding pea varieties are clustered in groups 3 and 4. Thus, despite the significant increase in area in which pea is grown in Spain, yields have been decreasing during the past years, which could be caused by the drought that the South of Europe is currently suffering. Hence, there is considerable interest in Spain in new pea varieties, particularly winter peas, which could establish their yield potential before the damaging summer drought and the hot dry weather in July, which causes losses during harvest.

This study indicates that there is enough genetic diversity in the unimproved germplasm group to select pea varieties with shortened internodes and dwarf plant architecture, which are desirable traits for earliness. Dumoulin et al. (1994) showed that a pea crop with high and stable productivity can be defined by its flowering earliness and a medium number of reproductive nodes. Earliness is an important trait in the South of Europe because two pea crops could be produced each year (winter and spring peas). Spring peas, especially those varieties with a long vegetative period, could be affected by powdery mildew caused by *Erysiphe polygoni*. Winter peas seem promising for yield potential improvement, if standing ability is also improved. Emphasis can also be placed on quality of peas for human consumption, which could be further improved by plant breeding. Breeding programs focussed on developing pea cultivars with long, very thick and tender edible pods could be considered a good strategy to encourage expanded consumption of vegetables, and may offer some possibilities for expanded commercial production and use. Another promising route for future pea breeding for vegetable types may be the introduction of new pea forms with multi-seeded pods and very small tender seeds.

In this study, an important environmental effect was noted on protein concentration, canopy traits, pod length and agronomic traits. The low variability observed among environments for reproductive characteristics (seed and vegetable quality traits), supports the hypothesis that development is under genetic control and little affected by environmental conditions (Ron and Ordas 1987; Ney and

Table 7. Mean squares of the combined analyses of variance over two seasons and 2 yr, mean, standard error, coefficient (CV) and range of variation for agronomic traits in the pea unimproved varieties studied

	Agronomic traits	
Source of variation	Days to flowering	No. seeds/pod
Seasons	2792.7	275.82
Locations	145370.5*	20.98
S × Locations[z]	495.9*	37.39*
Replications (S × L)[z]	33.6*	3.69**
Varieties	2010.0**	5.35**
Unimproved	1876.3**	5.49**
Elite	990.2	4.12
U-C[z]	25091.2**	1.68*
Varieties × S	137.4**	1.04
U × S	133.9**	0.80
C × S	117.6	3.89*
U-C × S	675.1**	0.00
Varieties × L	115.4**	0.74
U × L	103.5**	0.66
C × L	100.3	1.78
U-C × L	1492.5**	0.06
Varieties × S × L	50.4**	0.92**
U × S × L	39.7	0.88**
C × S × L	149.7*	0.73
U-C × S × L	272.2*	6.78**
Error[y]	35.5	0.57
CV (%)	4.01	13.26
Mean		
Unimproved	150.4 ± 2.06	5.66 ± 0.262
Elite	131.5 ± 2.66	5.85 ± 0.331
Range of variation		
Unimproved	121.9 – 185.1	3.69 – 8.03
Elite	110.0 – 153.0	4.70 – 6.56

[z]S = seasons, L = locations, U = unimproved varieties and C = elite cultivars.
[y]Degrees of freedom for the error due to missing data: days to flowering = 450 and number of seeds per pod = 438.

Turc 1993). The number of G × E interactions differed greatly between both groups of germplasm. This confirms that elite germplasm has been subjected to selection pressure for most of the traits investigated.

Recent trends in breeding programs focussed on reducing plant matter in the pea crop, whether grown for harvesting, immediate processing or for dry seed production. The new generation of semi-leafless pea varieties has greatly improved standing ability. The results of this work confirm that most of the elite cultivars used in Spain belong to this group of pea varieties that have shortened internodes, reduced stipules, low numbers of branches and a high numbers of tendrils.

In conclusion, wide variability exists for seed and vegetable constituents in the unimproved pea varieties, and the range of pea cultivars for feed and food consumption could be increased and diversified. The lack of genetic diversity found in the elite germplasm may limit further progress. Selection and crossing within local germplasm would introduce more genetic diversity. Pea breeders must recognize the level of germplasm development and breeding they are currently working at and where they must look for further improvement. These decisions could vary dramatically among breeding programs, but the model should be constant. Hence, the breeding strategies at the base level, including local material, involve more time and effort with regard to evaluation, selection and future hybridization, but offer more possibilities for the generation of new materials in the long term. Breeding pure lines obtained from single unimproved plants with specific good characteristics could

Table 8. Mean squares of the combined analyses of variance over two and three environments, mean, standard error, coefficient (CV) and range of variation for seed quality traits in the pea unimproved varieties studied

	Agronomic traits	
Source of variation	Days to fresh seed maturity	Days to fresh pod maturity
Environments	189545.32**	196932.37**
Replications (E)[z]	4.77	88.09
Varieties	688.19**	809.05**
Unimproved	676.55**	791.03**
Elite	39.22	45.40
U-C[z]	7739.68**	9556.27**
Varieties × E	214.20**	439.30**
U × E	205.44*	431.57**
C × E	33.84	16.68
U-C × E	2370.28*	5047.33**
Error[y]	32.78	57.92
CV (%)	2.82	10.60
Mean		
Unimproved	204.2 ± 2.80	188.2 ± 3.82
Elite	185.5 ± 3.36	167.7 ± 3.77
Range of variation		
Unimproved	182.0 – 227.0	157.0 – 220.0
Elite	158.0 – 192.0	157.0 – 177.0

[z]E = environments, U = unimproved varieties and C = elite cultivars.
[y]Degrees of freedom for the error due to missing data: days to fresh seed maturity = 209 and days to fresh pod maturity = 215.

Table 9. Mean squares of the combined analyses of variance over one environment, mean, standard error, coefficient (CV) and range of variation for agronomic traits in the pea unimproved varieties studied

	Agronomic traits		
Source of variation	No. pods/plant	Seed yield (g/plant)	Pod yield (g/plant)
Replications	1038.2	8399.9**	760.9
Varieties	407.0**	1457.4**	1261.0**
Unimproved	406.8**	1419.6**	1160.2**
Elite	108.1	996.3	2757.3*
U-C[z]	3113.7	9537.6*	0.0
Error[y]	140.5	774.7	620.2
CV (%)	36.32	30.03	40.34
Mean			
Unimproved	33.7 ± 7.99	74 ± 20.1	61 ± 17.9
Elite	19.8 ± 12.40	49 ± 13.4	59 ± 11.9
Range of variation			
Unimproved	13.0 – 72.0	26 – 172	17 – 143
Elite	10.5 – 34.5	23 – 107	27 – 163

[z]U = unimproved varieties and C = elite cultivars.
[y]Degrees of freedom for the error due to missing data: number of pods per plant = 112, seed yield = 110 and pod yield = 108.

Table 10. Ranges of variation of seed quality, canopy, vegetable quality and agronomy traits per group of unimproved varieties

	Unimproved variety groups									
Traits	1	2	3	4	5	6	7	8	9	10
Seed quality traits										
Protein concentration	22.80–23.78	21.08–23.46	21.50–23.10	20.30–24.23	21.88–22.38	21.18–22.65	20.92–23.28	21.35–22.40	23.35	22.34
Soluble sugars	12.4–14.3	10.3–13.7	10.0–13.4	10.5–14.4	10.0–14.1	9.1–11.9	8.7–11.6	9.6–9.9	9.6	10.7
Tenderness	13.7–17.3	10.3–15.5	10.6–17.1	10.5–15.3	11.2–15.8	8.3–14.4	9.5–16.6	11.3–13.4	12.5	12.7
Fresh size	10.03–10.38	7.85–10.37	7.17–8.55	8.07–10.52	8.08–10.16	7.37–8.79	8.96–10.21	8.71–9.78	9.53	9.74
Fresh weight	24.7–29.3	16.8–25.0	10.2–18.7	15.1–26.0	15.9–25.0	11.8–22.5	18.3–26.8	19.8–23.3	24.8	20.9
Canopy traits										
Internode length	5.5–9.2	4.9–11.3	7.8–9.5	4.9–12.6	7.7–10.9	7.0–11.3	8.5–12.1	10.2–10.5	9.6	11.5
Length first flower	53–99	60–190	116–141	55–227	78–120	87–233	111–214	132–179	119	195
No. basal branches	1.17–1.99	1.33–3.53	1.89–4.06	1.10–3.78	1.70–1.72	2.63–5.43	1.47–3.40	1.90–3.70	1.57	3.17
Leaflet length	3.88–4.61	4.03–5.61	4.08–5.21	3.90–6.31	0.00–4.71	4.03–5.76	4.42–5.95	4.37–5.90	3.97	5.69
Leaflet width	2.75–4.37	2.20–3.54	2.20–3.69	2.16–4.37	0.00–3.40	1.96–3.07	2.72–3.98	2.57–3.26	3.00	3.87
Stipule length	7.51–8.83	6.84–9.16	7.03–8.65	6.96–9.86	6.12–8.54	6.74–9.45	7.81–10.46	7.35–9.76	7.29	10.02
Stipule width	4.48–5.12	3.73–5.37	3.44–4.44	3.93–5.77	3.18–5.49	3.52–5.29	4.22–6.30	4.27–5.53	4.36	6.11
No. tendrils	5.60–6.60	4.85–6.38	5.30–6.28	4.75–6.50	6.18–9.31	4.99–6.13	4.73–5.95	5.30–5.78	5.18	5.35
No. leaflets	4.12–4.70	3.73–5.08	4.73–5.10	3.83–5.63	0.00–5.28	3.78–5.18	4.08–4.85	4.05–4.95	4.15	4.43
Node first flower	9.45–12.16	11.25–16.09	12.81–17.02	12.19–18.30	10.65–11.73	11.59–20.55	12.66–16.54	13.50–15.88	12.94	16.14
Vegetable quality traits										
Abortions	18.8–36.1	18.2–37.9	28.2–40.0	17.1–48.4	15.6–32.2	16.9–44.6	12.7–31.0	13.6–26.8	20.0	8.3
Fresh weight	3.07–3.75	1.54–2.94	0.71–2.49	1.23–2.71	1.42–3.25	0.79–1.55	1.81–4.20	1.70–2.24	4.88	2.97
Length	76.9–87.9	62.8–82.8	51.0–69.5	60.0–82.1	53.3–81.7	56.1–66.3	76.3–101.5	64.5–81.4	105.1	93.0
Width	18.7–19.5	15.1–17.5	10.7–20.0	12.6–17.6	14.8–19.0	11.4–14.4	14.8–21.8	15.3–15.8	21.4	17.1
Agronomic traits										
Days to flowering	122.8–133.0	128.0–167.5	130.6–172.4	127.5–174.3	121.9–135.9	134.9–185.1	140.5–165.6	143.0–152.9	133.4	168.0
Fresh seed maturity	185.0–192.3	182.3–225.0	188.8–222.0	182.5–226.7	187.5–188.8	207.5–225.0	190.0–217.0	196.8–215.3	187.5	217.8
Fresh pod maturity	157.3–171.8	167.8–204.3	162.7–210.3	165.0–214.5	171.3–174.3	192.0–220.0	170.8–205.3	177.3–194.8	168.3	195.8
Pods per plant	14.3–16.1	13.7–45.1	15.9–66.6	13.8–72.7	14.8–18.1	25.4–69.3	13.4–39.8	38.0–49.5	20.7	27.3
Seeds per pod	5.70–7.38	4.38–6.93	4.53–6.54	3.69–7.85	4.63–6.75	4.10–6.75	5.03–6.74	5.48–6.95	6.36	6.33
Seed yield	39–59	39–106	41–143	36–172	26–104	46–134	41–125	110–129	63	88
Pod yield	30–44	39–89	27–116	25–120	18–44	27–84	31–143	57–90	95	72

be incorporated into new crossing programs. The most important current breeding goal is to encourage the use of the new pea varieties to improve the productivity and the competitiveness of the crop in Europe.

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