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# Effects of planting season and plant cultivar on growth, development, and pod production in snap bean (*Phaseolus vulgaris* L.)

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**Abstract.** The effects of cultivar and planting season on growth development and pod yield of snap bean (*Phaseolus vulgaris* L.) were analysed in a 2-year, 2-location experiment in Spain. Phenology, pod production, and quality differed significantly among snap bean cultivars. Planting season had a significant effect on most pod traits except the number of seeds per pod, length, thickness, soluble solids content, tenderness, and string, and this effect varied markedly among environments. High and negative correlations for vegetative growth traits between early and late planting seasons confirmed the strong planting season influence on those traits. Fresh pod yields were highest in the early planting season, and the longer pod maturation phase could be considered to be one of the main factors. Planting of snap bean earlier in the season should thus contribute to a longer growing vegetative cycle and greater productivity than normal or summer and late autumn planting. The earliest maturing snap bean cultivars would have the highest fresh pod yields in late planting seasons, while the latest maturing snap bean cultivars would have the highest yields in early and normal planting seasons. These results will allow breeders to optimise the level of earliness for each planting season without reducing the yield. This is a key requirement for snap bean crops, and it is the first step towards selecting parental lines with stability of pod traits to be used in breeding programs for different growing areas and planting seasons.

**Additional keywords:** precocity, germplasm, pod set, pod yield, breeding.

## Introduction

Snap bean (*Phaseolus vulgaris* L.) is defined by its pod characteristics and has fewer and less distinct market classes than dry bean (Skroch and Nienhuis 1995; Santalla *et al*. 2001*a*), but given its importance as a vegetable, breeders have developed many cultivars. Names such as Romano, Green bean, or Wax bean (also known as Italian or Flat pod beans) describe the different market classes (Cunha *et al*. 2004). Romano bean pods are green coloured, with flat cross-sectional shape, and are relatively fibre-free. Green bean has fleshy pods that are generally oval to round in cross-section. Wax bean pods have a shape similar to Green or Romano bean pods, but they are pale yellow to golden (Myers and Baggett 1999).

Snap bean varieties are currently classified as those with fleshy pods and those with slender pods. They can be grouped into (*i*) fresh market types, bush and pole beans with green and yellow slender and fleshy pods; and (*ii*) processing types, bush beans with slender and fleshy green and yellow pods, and both with white and coloured seeds. White-seeded types are grown extensively for the processing industry because pigmented seed coats could colour the liquor in the can, and this is considered unattractive for the consumer (Ross *et al*. 1956). However, this is not a problem for the frozen product. Types suited to the long-distance shipping trade have been developed recently. These are high-fibre bean pods that can be kept several days at ambient temperatures without becoming wrinkled or flaccid.

Snap beans are commercially produced in larger quantities in developed countries (predominantly the United States, China, Japan, Spain, Italy, and France), where diets are more varied than in less developed countries. Spain produced $220 \times 10^3$ t of snap beans on $15 \times 10^3$ ha in 2007 (www.mapya.es/es/estadistica/infoestad.html), with 28.355 t for export. Pole dark green flat or round-pod beans rank among the most important fresh vegetables in Spain ($199 \times 10^3$ t), followed by canned and frozen ($40 \times 10^3$ t) products. Yellow pod snap beans are grown on limited areas as speciality vegetables. In general, the consumption of canned products is decreasing while fresh snap bean consumption is increasing. Snap beans are produced in many areas of Spain. The main production areas are: the south coast (Almería, Granada, and Malaga Provinces), $110 \times 10^3$ t on $7 \times 10^3$ ha; the Central Valley (La Rioja), $19 \times 10^3$ t on $2 \times 10^3$ ha; the north-west (Galicia), $43 \times 10^3$ t on $2 \times 10^3$ ha; and the north-east (Cataluña), 943 t on $12 \times 10^3$ ha. Production is timed for the late planting season, planted about August and harvested from October to the beginning of the frosts; the early planting season, planted on February and harvested from March to May; and the normal planting season, planted through April and harvested from June to July. Crop production is harvested by a single picking.

Snap beans are an excellent crop to make the transition from agriculture to horticulture. Cultural practices for snap beans are related to, but more intensive than, those for dry

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beans. Research efforts to improve snap bean cultivars and cultural practices have focussed on stable yields, earliness, disease resistance, tolerance to environmental stresses, and desirable agronomic-horticultural attributes (Traka-Mavrona *et al.* 2000). Snap bean breeding began in ~1890 in America and focussed on early bean varieties with stringless pods. Today, all varieties of edible-podded beans grown are stringless at the harvest stage. Much of the genetic improvement of snap bean has been achieved by applying conventional breeding techniques of self-pollinated crops such as bulk, pedigree, backcross, and the single-seed descent methods (Myers and Baggett 1999; Tofiño and Ocampo 2003). While the genetic base may be fairly broad, the incorporation of traits from a non-snap bean background takes time and persistence. A specific challenge for the breeder is to develop yellow slender pod snap beans with an increasing pod size while retaining yield.

Much of the environmental variation in yield of snap bean and other legume crops is associated with variation in pods and seeds per unit area (Jong *et al.* 1982; Pandy *et al.* 1984; Egli 1998). The number of pods and seeds at maturity is related to the productivity of the crop during flowering and seed set. The manipulation of planting season or cultivar (de la Vega *et al.* 2001) always caused corresponding changes in pod and seed number. It is also well known that the highest quality of snap beans is reached in advance of maximum yield (Gardiner and Prendville 1970). Pods harden as they mature, becoming rich in fibre and less palatable. Harvest time (Ferreira *et al.* 2000) should be set to obtain the greatest yield compatible with good pod quality, if nutrients do not limit plant growth. Therefore, among the different factors affecting yield, planting season usually has a predominant influence.

Planting season is one of the most important agronomic factors involved in producing high yielding crops worldwide. The scope for improving vegetable production through suitable planting season and bean cultivar combinations has not yet been fully exploited. In this study, the effect of planting season on snap bean cultivars was examined in different environments with temperature conditions representative of many growing areas. The objectives of the present research were: (*1*) to study the effects of different planting seasons on the development, growth, and yield of snap beans and their interaction with cultivar; and (*2*) to identify the optimal planting season under different environments for snap bean in order to raise its potential as a profitable horticultural crop.

## Materials and methods

### Field and greenhouse experimental design

Thirty-five local and five control cultivars (Maravilla de Venecia, Oro del Rhin, Felisa, Maravilla de Venecia var. Rapid, and Dorada de Aragón) were chosen to represent a cross-section of the pole wax slender podded bean germplasm for fresh market. The snap bean cultivars were simultaneously grown for 2 years (2003 and 2004) at Salcedo (42°26′N, 8°38′W; 30 m) and Tomiño (41°59′N, 8°46′W; 40 m) locations in three planting seasons (Table 1). They were artificially supported by a wooden stake and a fibre string twine. The support height reflected the anticipated mature bean plant height. The average minimum and maximum temperatures and rainfall for each environment are displayed in Fig. 1. Inside the greenhouse, ventilation was provided automatically when the air temperature exceeded 25°C, and light was only provided by natural solar radiation. The experimental plots were thinned 15 days after sowing or transplanting to the standard (25 000 plants/ha) crop density population. The plots were one 4-m row of each cultivar with two replications in each experiment for a completely randomised design. The plots were irrigated to minimise water stress and a commercial fertiliser preparation (15-15-15) was applied as needed for maximum growth. Diseases and pests were controlled as far as possible in all experiments, and weed control was carried out as required.

**Table 1. Basic information on each planting season experiment for all snap bean cultivars grown in 4 environments (2 years and 2 locations)**
The experiment carried out at Tomiño in 2004 in the normal planting season was lost

| Planting season | Cultural step | Planting dates Salcedo | Planting dates Tomiño |
|---|---|---|---|
| Normal | Open field | 15 May 2003 | 13 June 2003 |
| *Spring–summer* | Seed sowing | 14 May 2004 | |
| Late | Unheated plastic greenhouse | 17 Sept. 2003 | 1 Sept. 2003 |
| *Summer–autumn* | Transplanting | 27 Aug. 2004 | 23 July 2004 |
| Early | Unheated plastic greenhouse | 21 Feb. 2003 | 20 Feb. 2004 |
| *Winter–spring* | Transplanting | 20 Feb. 2004 | 10 Mar. 2004 |

### Flowering and podding harvest time

For each planting season and environment, the start and end of flowering and podding harvest of each snap bean cultivar were recorded.

### Pod production and pod set

The temporal distribution of pod development was recorded at 3-day intervals to bracket the optimal fresh pod production for each snap bean cultivar. For each cultivar, all pods with the same date were combined for counting and weighing. Pod length, width, and thickness (mm), and number of seeds per pod were measured on 20 random fresh pods per plot. Pod intensity of ground colour (light, medium, and dark), length of beak (1–9, where 3 = short, 5 = medium, and 9 = long), curvature of beak (1 = absent or very weak, 3 = weak, 5 = medium, 7 = strong, and 9 = very strong), texture of surface (1–9, where 3 = smooth, 5 = medium rough, and 9 = rough), and suture string (1 = stringless to 9 = very stringy) were estimated from a sample of 20 random fresh pods per plot. Total soluble solids were determined when the pod was crushed, and the refractive index on the expressed juice was measured with a refractometer (RHB-32ATC-Huake). Pod breakage determination or tenderness ($kg/cm^2$.72 or pounds/square inch) was measured by using a blender method consisting of grinding 50 g of a cooked pod sample (Escribano *et al.* 1997). A seed index of fresh pods was recorded as [(seed weight/pod weight) × 100] × 100-seed length, and it was used to estimate snap bean quality grades (Silbernagel and Drake 1978). Fresh seed length was determined by taking one normal-looking seed from the middle of each pod in a 4-replicate random 10-pod

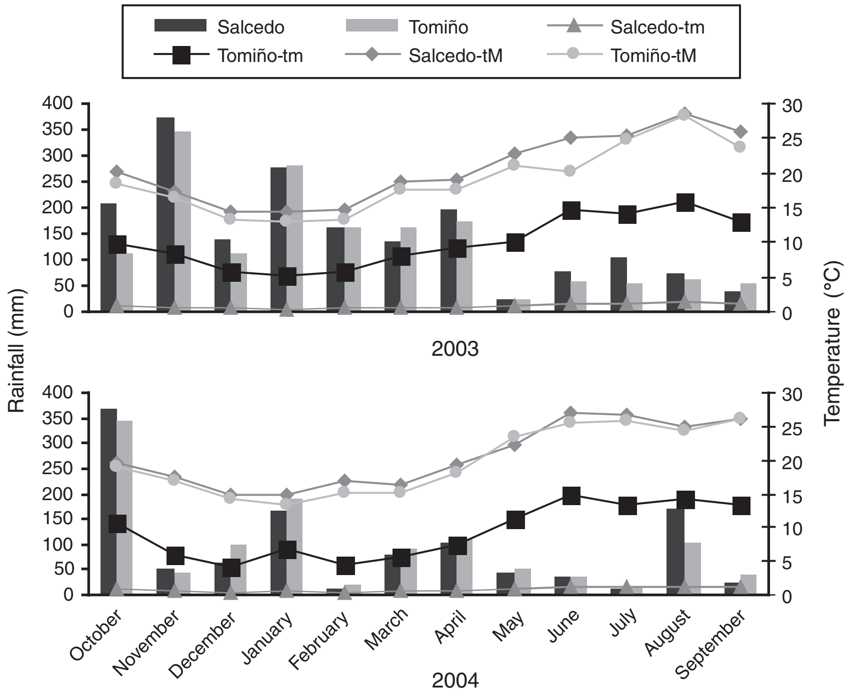


**Fig. 1.** Monthly maximum (tM) and minimum (tm) temperatures (lines) and rainfall distributions (bars) in 2003 and 2004 at Salcedo and Tomiño locations.

sample. Both fresh seed length and percentage of seed by weight have been considered useful maturity indices for processed snap beans.

### *Statistical analysis*

Analyses of variance were carried out by established methods (Steel *et al*. 1997) using the PROC GLM procedure of the SAS Statistics package (SAS Institute Inc. 2000). Several traits required transformation to improve the homogeneity of the error variance. Data from the beginning and end of podding harvest and pod yield were transformed by logarithmic transformation (Menkir and Larter 1987). The environments and cultivars were considered as random effects, while the planting seasons were fixed effects. Cultivar and environment mean differences within each planting season were separated using Fishers' protected least significant difference (l.s.d.) test at $P \leq 0.05$. Spearman rank correlation coefficients between traits were obtained for each pair of planting seasons. A principal component analysis was performed on the standardised variables using PROC PRINCOMP.

## Results

### *Phenology, pod production, and quality under different environments and planting seasons*

Air temperature during the late planting season averaged $14.2 \pm 1.5$°C in both years and locations (Fig. 1). In the early and normal planting seasons, air temperatures averaged $13.0 \pm 0.5$°C and $19.3 \pm 0.5$°C, respectively. The normal planting season received 70 mm and 48 mm of precipitation in Salcedo and Tomiño, respectively, in 2003. In 2004, all sites received ~60 mm of precipitation during the normal planting season. Although the total rainfall was greater in 2003 than in 2004, the rainfall was more evenly distributed during the growing season of 2003.

A combined analysis was conducted to determine the importance of environment, planting season, cultivar effects, and interactions (Tables 2 and 3). The cultivar × environment × planting season interaction was significant for most of the traits studied except the days to the beginning of flowering, pod tenderness, string, and the seed index, suggesting that the cultivars differed in tolerance to planting season and adaptation to the environment. A significant cultivar × planting season interaction was observed for the days to beginning of flowering and podding harvest, number of seeds per pod, pod width and thickness, and the seed index. This interaction was generally more variable than the cultivar × environment interaction, which was only found significant for the beginning of flowering. The duration of the vegetative growth differed significantly among cultivars, as well as pod production and quality. Significant environmental effects were noted for all traits except pod width, thickness, soluble solids content, and string, and presumably they were due to variations in temperature and rainfall among environments. Planting season had a significant effect on many traits except the number of seeds per pod (average of 5.2), pod length (153.4 mm), thickness (6.12 mm), soluble solids content (4.7%), tenderness (110 kg/ $cm^2$.72), and string (2.7). In the early planting season, the beginning of flowering and podding harvest time were

**Table 2. Mean squares from the analysis of variance for reproductive efficiency traits and fresh pod production of all snap bean cultivars in 3 planting seasons grown in 4 environments**

*P < 0.05; **P < 0.01

| Sources of variation | d.f. | Start of flowering | Start of pod harvest | End of pod harvest | No. of seeds/pod | Fresh pod yield |
|---|---|---|---|---|---|---|
| Planting season (P) | 2 | 34536.66** | 50276.54** | 75696.01** | 59.920 | 11555498.17** |
| Environment (E) | 3 | 3799.59** | 6890.17** | 2305.91** | 97.046** | 12348877.24** |
| E × P | 4 | 6139.93** | 11221.09** | 14235.55** | 21.291** | 3288829.43** |
| Blocks (E × P) | 12 | 6.38 | 25.28 | 54.32 | 0.913** | 146485.91 |
| Cultivar (C) | 39 | 58.49** | 78.33** | 163.88** | 4.114** | 428917.83** |
| Cultivar × P | 78 | 53.61** | 57.50** | 104.87 | 1.023** | 188693.85 |
| Cultivar × E | 117 | 27.92* | 31.36 | 73.37 | 0.529 | 167663.57 |
| Cultivar × E × P | 234 | 19.30 | 31.55** | 81.68** | 0.628** | 150705.58** |
| Pooled error | 479 | 15.97 | 19.32 | 31.60 | 0.275 | 92433.21 |
| $R^2$ | | 0.95 | 0.97 | 0.96 | 0.91 | 0.83 |
| CV (%) | | 7.03 | 5.59 | 4.81 | 10.07 | 60.42 |

**Table 3. Mean squares from the analysis of variance for pod set traits of all snap bean cultivars in 3 planting seasons grown in 4 environments**

*P < 0.05; **P < 0.01

| Sources of variation | d.f. | Length | Width | Thickness | Soluble solids | Tenderness | String | Seed index |
|---|---|---|---|---|---|---|---|---|
| Planting season (P) | 2 | 1976.08 | 198.51* | 2.21 | 2.154 | 12160.83 | 16.612 | 2323838.09** |
| Environment (E) | 3 | 11957.88** | 11.49 | 2.82 | 1.279 | 48596.86* | 3.041 | 491019.56** |
| E × P | 4 | 13038.92** | 21.79** | 2.60** | 10.399** | 7260.28** | 12.209** | 445123.26* |
| Blocks (E × P) | 12 | 247.72 | 1.27 | 0.16 | 0.633* | 595.16 | 1.041 | 39530.42 |
| Cultivar (C) | 39 | 23924.49** | 22.73** | 3.70** | 1.053** | 1083.94** | 7.891** | 72365.92** |
| Cultivar × P | 78 | 273.73 | 2.44* | 0.28* | 0.527 | 551.26 | 1.073 | 43805.88** |
| Cultivar × E | 117 | 221.19 | 1.69 | 0.21 | 0.424 | 507.75 | 0.879 | 19790.05 |
| Cultivar × E × P | 234 | 213.76** | 1.69** | 0.22** | 0.423** | 466.18 | 1.029 | 18428.58 |
| Pooled error | 479 | 149.16 | 0.98 | 0.13 | 0.284 | 501.17 | 0.927 | 20870.99 |
| $R^2$ | | 0.96 | 0.87 | 0.87 | 0.73 | 0.78 | 0.73 | 0.82 |
| CV (%) | | 7.97 | 6.14 | 5.87 | 11.53 | 20.05 | 38.20 | 48.10 |

retarded, and fresh pod production was doubled. The seed index was also different between both the 2-year sites, and it was higher in the early and normal planting seasons than in the late planting season (Table 4, significant data shown).

On the other hand, the influence of the planting season on growth development, pod production, and quality varied markedly among environments (Table 5, significant data shown). Thus, in 2004 in both locations, the beginning of flowering and podding harvest were markedly retarded in the early planting season. However, delaying snap bean maturity by 2 weeks did not result in a shorter growth development. Tomiño environments provided the best conditions for snap bean growth and gave the highest production values in the early planting season, with a total average of 944 and 1430 g/plant in 2003 and 2004, respectively. A comparison between all groups of values revealed that climate differences between years had a less marked effect on pod yield than locations. Pod length, thickness, soluble solids content, tenderness, and string showed large but non-consistent differences among planting seasons over years and sites. The late planting season showed the widest pods at both sites and years, and it also gave the lowest seed index.

Correlations between early, normal, and late planting seasons for flowering and podding harvest, pod yield, and quality are summarised in Table 6. Correlations between early and late planting seasons for the beginning of flowering (–0.56**) and podding harvest (–0.80**) and the end of podding harvest (–0.55**) were high and negative. The values of rank correlations for these traits between the other pair of planting

**Table 4. Effect of planting season on pod traits of all snap bean cultivars in 3 planting seasons grown in 4 environments**

Within columns, means followed by the same letter are not significantly different according to l.s.d. at $P = 0.05$

| Planting season | Start of flowering | Start of pod harvest | End of pod harvest | Fresh pod yield | Pod width | Seed index |
|---|---|---|---|---|---|---|
| Early | 68a | 94a | 135a | 761a | 16.16ab | 358a |
| Normal | 53ab | 72ab | 106ab | 308b | 15.08b | 497a |
| Late | 46b | 66b | 104b | 369b | 17.17a | 191b |

**Table 5. Pod traits of all snap bean cultivars as affected by planting season in 4 environments**

Within rows, means followed by the same letter are not significantly different according to l.s.d. at $P = 0.05$

| Environment | Planting season | | |
|---|---|---|---|
| | Early | Normal | Late |
| *Beginning of flowering (days)* | | | |
| Salcedo 2003 | 56a | 55b | 52c |
| Salcedo 2004 | 71a | 53b | 42c |
| Tomiño 2003 | 59a | 53b | 43c |
| Tomiño 2004 | 84a | 52b | 44b |
| *End of podding harvest (days)* | | | |
| Salcedo 2003 | 123a | 120b | 114c |
| Salcedo 2004 | 135a | 97c | 109b |
| Tomiño 2003 | 143a | 97b | 106c |
| Tomiño 2004 | 145a | 97b | 89b |
| *No. of seeds per pod* | | | |
| Salcedo 2003 | 4.2b | 6.0a | 3.8b |
| Salcedo 2004 | 5.1b | 6.1a | 5.2b |
| *Fresh pod yield (g/plant)* | | | |
| Salcedo 2003 | 599a | 394b | 98c |
| Salcedo 2004 | 323a | 204b | 352a |
| Tomiño 2003 | 944a | 321b | – |
| Tomiño 2004 | 1430a | – | 671b |
| *Length (mm)* | | | |
| Salcedo 2003 | 140.28b | 161.26a | 130.14c |
| Salcedo 2004 | 147.58b | 153.73b | 165.96a |
| *Width (mm)* | | | |
| Salcedo 2003 | 16.41b | 15.24c | 17.24a |
| Salcedo 2004 | 15.79b | 14.97c | 18.04a |
| Tomiño 2003 | 16.28a | 14.99b | 15.11b |
| *Thickness (mm)* | | | |
| Salcedo 2003 | 6.18a | 5.98b | 5.74c |
| *Soluble solids (%)* | | | |
| Salcedo 2003 | 5.09a | 4.64b | 4.31c |
| Salcedo 2004 | 4.22b | 4.97a | 4.78a |
| *Tenderness (kg/cm$^2$.72)* | | | |
| Salcedo 2003 | 109a | 102b | 64c |
| *String* | | | |
| Salcedo 2003 | 2.14b | 2.29b | 3.51a |
| *Seed index* | | | |
| Salcedo 2003 | – | – | 128.92 |
| Salcedo 2004 | 276b | 497a | 184c |
| Tomiño 2003 | – | – | – |
| Tomiño 2004 | 493a | 513a | 220b |

seasons were low, except the end of podding harvest. Positive correlations were observed between early and late planting seasons for the number of seeds per pod (0.35**), fresh pod yield (0.19**), and the seed index (0.39**), and between early and normal planting seasons for tenderness (0.39**). Pod dimensions showed high and positive rank correlation values between all the pairs of planting seasons. The low values of the correlation coefficients for most of the pairs of planting seasons evaluated (early *v.* normal planting seasons and normal *v.* late planting seasons), and the significant cultivar × planting season interaction observed for flowering, podding harvest, and fresh pod production, confirm the strong planting season influence that could complicate the breeder's quest for genetic progress and yield stability. However, the high and negative values of correlation found for flowering and podding harvest between early *v.* late planting seasons must be taken into account to select elite snap bean cultivars for further testing, and suggest that the flowering and maturity performance of the snap bean cultivars differed with the planting season.

### Temporal profiles of pod production

The temporal pattern of pod production was significantly different among the planting seasons (Fig. 2), with production rising to a maximum ~113 days after sowing in the early planting season and then declining. The maximum pod production varied ~89–98 and 93 days after sowing in the late and normal planting seasons, respectively. Most of the pods were produced in a relatively long interval (73–131 days) after sowing in the early planting season, while in the normal and late planting seasons this interval varied between 73 and 113 days after sowing. The temporal pattern of pod production in Salcedo in 2003 was different from 2004 (Fig. 3). The period for podding harvest in the early planting season in Salcedo was 73–131 and 78–129 days after sowing, with production rising to a maximum at 122 and 110 days after sowing, in 2003 and 2004, respectively. The patterns for podding harvest in the early planting season in Tomiño were 93–131 and 73–110 days after sowing in 2003 and 2004, respectively. The peak production was at 110 and 84–98 days after sowing in 2003 and 2004, respectively. The temporal distribution of pod production in the normal planting season during the period 2003–04 was 73–131 and 78–113 days after sowing in Salcedo, and 73–105 days after sowing in Tomiño. The peak production in the normal planting season was slightly earlier in Tomiño in 2003 than in Salcedo in 2004 (~93 days after sowing) and in 2003 (101 days after sowing). There were

**Table 6. Spearman's coefficient of rank correlations of pod traits across planting seasons**

$^{*}P < 0.05$; $^{**}P < 0.01$

| Comparison | Start of flowering | Start of pod harvest | End of pod harvest | No. of seeds per pod | Fresh pod yield | Length | Width | Thickness | Soluble solids | Tenderness | String | Seed index |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Early *v.* normal planting season | –0.05 | 0.13 | –0.59** | 0.11 | 0.14* | 0.82** | 0.52** | 0.56** | –0.07 | 0.39** | 0.15* | 0.19 |
| Early *v.* late planting season | –0.56** | –0.82** | –0.55** | 0.35** | 0.19** | 0.83** | 0.35** | 0.46** | –0.25** | 0.27** | 0.09 | 0.39** |
| Normal *v.* late planting season | 0.21* | 0.39** | 0.18* | 0.35** | –0.22* | 0.69** | 0.37** | 0.61** | 0.27** | 0.21 | 0.09 | 0.02 |

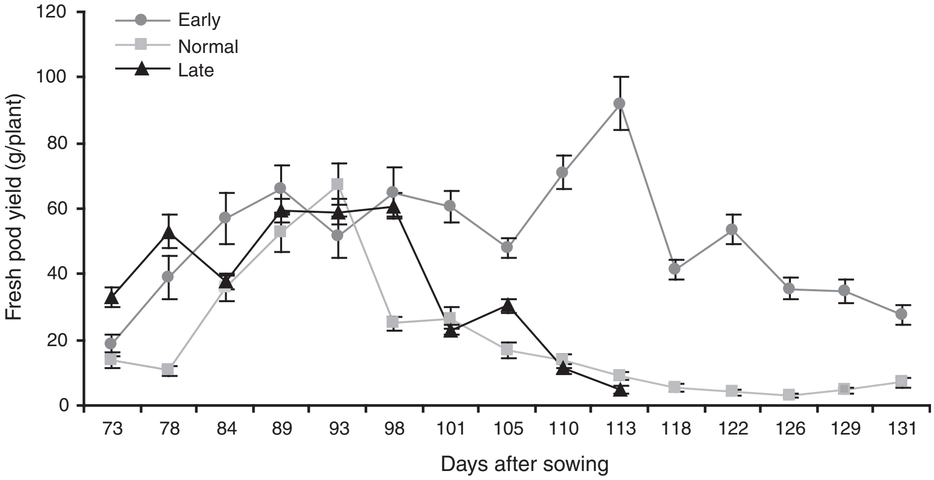


**Fig. 2.** Seasonal trend of fresh pod production for the planting seasons (vertical bars indicate the standard error).

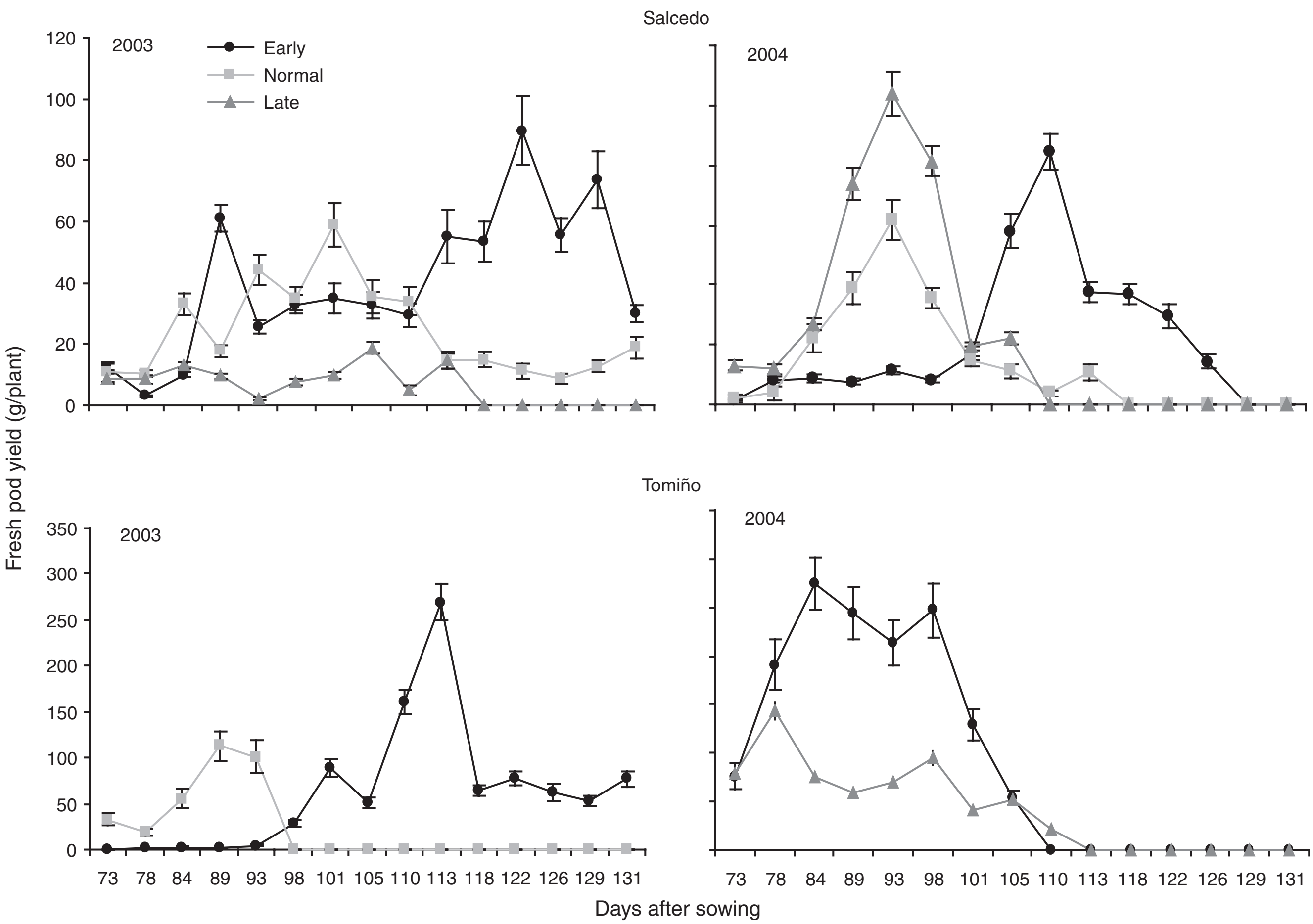


**Fig. 3.** Seasonal trend of fresh pod yield for the planting seasons and environments (vertical bars indicate the standard error).

differences among the patterns of pod production in the late planting season in both years and sites. For the late planting season, the period from the beginning of the podding harvest was 73–118 and 73–100 days after sowing in Salcedo during 2003 and 2004, respectively, and 73–110 days after sowing in Tomiño. The peak production was 93 and 78 days after sowing in Salcedo and

Tomiño, respectively, while in 2003, this was 105 days after sowing. The delay in the peak of main production was lower when the snap bean crop was planted late. All snap bean cultivars showed decreased yields at the last harvest date, which indicates that yields based on weight decrease when the optimum stage of maturity has been exceeded.

### *Relationships among vegetative growth, fresh pod production, and quality*

Seed index was weakly positively correlated with the days to the beginning of flowering, beginning of podding harvest, and end of podding harvest in the early ($r^2 = 0.36$, $r^2 = 0.45$, $r^2 = 0.35$) and normal ($r^2 = 0.33$, $r^2 = 0.45$, $r^2 = 0.20$) planting seasons. Fresh pod yield was inversely proportional to the time to vegetative growth in the late planting season, with $r^2 = -0.50$, $r^2 = -0.64$, and $r^2 = -0.49$ for the days of the beginning of flowering, and the beginning and end of podding harvest, respectively.

In general, increase in pod width (across all snap bean cultivars and 4 environments) decreased the seed index value, with $r^2 = -0.29$, $r^2 = -0.50$, and $r^2 = -0.31$ for the early, normal, and late planting seasons, respectively. The widest pod cultivars developed little fibre or seed index under these environmental conditions. In general, the increase in pod width (across 12 environments and 40 cultivars of snap bean) decreased the seed index. Most control cultivars (Oro del Rhin, Maravilla de Venecia, Felisa, and Maravilla de Venecia var. Rapid) had a low seed index value in contrast to the local snap bean cultivars.

### *Cultivar variability for reproductive efficiency, fresh pod production, and pod set*

Figure 4 shows cultivar variability for the morphological and agronomic pod traits studied. In the principal component analysis, the first two principal components accounted for 42% of the variation in pod traits. The following groups of cultivars are evident in the analysis: (*1*) 10 cultivars (including the control cv. Dorada de Aragón), producing large sieve pods (19–22 cm) with long and curved pod beaks, higher pod fibre development, and a rough textured pod surface; (*2*) 2 cultivars, based on a high presence of fibre in both pod sutures and thicker pods (8 mm), which were separated from (*3*) 7 cultivars (including the control cv. Felisa) that developed the widest pods with presence of a secondary light green pod colour. Snap bean cultivars that had the highest fresh pod yields in all environments and a fast rate of pod development were identified in the last two groups. The (*4*) 2 control cultivars, Oro del rhin and Maravilla de Venecia, produced distal truncated shaped pods, and were separated from the (*5*) 5 cultivars producing the highest pod sugar concentrations, with the presence of pigmented flowers, stems, and a concave curvature pod shape.

## Discussion

### *Duration of vegetative growth under different planting seasons and environments*

The length of the flowering and pod-production period was significantly variable among cultivars, planting seasons, and environments. The snap bean crop in the early planting took slightly longer to flower and mature than in the other planting seasons. As expected, the later the snap bean crop was planted in the year, the shorter was the time to reach flowering and maturity. However, the earliest snap bean crop was planted (23 July) in the late planting season and the latest snap bean crop was planted (13 June) in the normal or summer planting season, hastening its development. This fact was due to the extreme cold (~6°C during

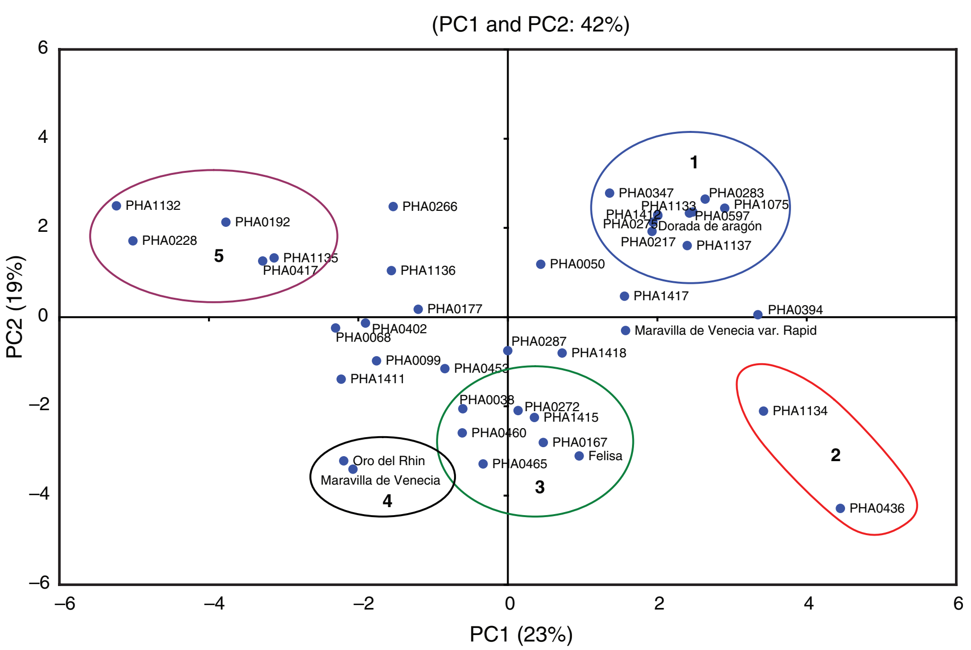


**Fig. 4.** Principal component analysis of variability for morphological and agronomic traits of snap bean cultivars.

maturity) and warm temperatures (~28°C during maturity) in the early and late planting seasons, respectively, and thus, phenological development was accelerated. Moreover, there might have been confounding effects of various environmental factors on the development of snap bean; therefore, the effect of planting season on cultivar was not significant for the end of podding harvest (Santalla *et al*. 2001*b*; Singh *et al*. 2007; Nakano *et al*. 2008).

### *Pod production and its components*

Pod yields were higher in the early planting season than in the normal and late planting seasons, and were higher in Tomiño than in Salcedo at both years. The lower pod yield in the late planting season can be attributed to a smaller biomass production from a shorter vegetative growth period. There was not a significant planting season × cultivar interaction for pod yield, although significant planting season × cultivar × environment effects were shown. The normal and late planting seasons had 40–49% lower pod yields than the previous early planting season, but there was not a significant reduction in pod yield in the late planting at Salcedo in 2004. The planting season effect was also site-year specific. The early planting season had a higher pod yield than the other planting seasons, especially in Salcedo environments. The longer pod maturation phase in this planting season could be considered to be one of the factors causing high pod yield.

The pod production advantage (>50%) of the early (February–May) over the normal (May–August) or late (August–November) planting seasons strongly supported the hypothesis of this study. The temporal pattern of pod production was not similar in the open field (normal planting season) and greenhouse experiment (early and late planting seasons). Most of the pods were produced in a relatively longer interval in the early planting season, while this interval and the delay in the peak of main production were shorter in the other planting seasons. The temporal patterns of pod production in different environments and planting seasons did not change with increases in plant productivity, which suggests that the patterns were not controlled by assimilate availability. Alternatively, the decline in pod production may simply result from declining flower production as vegetative growth ceases. These results extend other previous reports (Egli and Bruening 2006; Yau 2007), which showed that the length of the flowering and pod production period was not as sensitive to the environment as plant density, but they were sensitive to other aspects such as planting season. Longer flowering and pod period were reported to increase pod production in soybean (Egli and Bruening 2000).

Our study showed a negative relationship between the flowering and maturity period and fresh pod yield in the late planting season. This suggests that across environments in late planting seasons, the earliest snap bean cultivars had the highest fresh pod yields. Based on the positive relationships in the other planting seasons, the highest fresh pod yields were observed in the latest flowering and maturing cultivars. Cultivars with long vegetative growth duration had generally higher fresh pod yields than those with short vegetative growth duration in the early and normal planting seasons. In this study the shortest snap bean cultivars for vegetative growth had the highest fresh pod yields in the late planting season.

### *Pod quality*

Pod traits are perhaps the most important aspects of snap bean cultivars, and these include colour (relative external and uniformity of colour), pod shape, length, and fibre content (Myers and Baggett 1999). Mean pod width values were greater in the late planting season (17 mm) than in the other planting seasons (15–16 mm) in both years and sites. Planting season and cultivar significantly affected the seed index; thus, the later the snap bean crop was planted, the lower was the seed index in all site-years. This might be associated with the fact that lower pod yields were observed in the latest snap bean cultivars. The normal planting season had a significantly higher seed index than the early and late planting seasons at Salcedo in 2003.

Optimum harvest maturity of snap bean has been based on several factors including texture, colour, general appearance, flavour, seed weight percentage, pod shape, pod length, ascorbic acid content, and sieve size distribution (Silbernagel and Drake 1978). These authors showed that fresh seed index was a good maturity index and it was positively correlated with fibre development of large- and medium-sieve snap pod cultivars. Thus, it is much easier and more efficient to determine this fresh seed index than fibre development. Other authors (Mullins and Coffey 1990) observed that the fresh seed length was only a good index of crop maturity for small-sieve pod cultivars. In this work, the seed index was useful in evaluating the product for small-sieve pod snap bean cultivars. Silbernagel and Drake (1978) showed a correlation between the fresh seed index and percentage of fibre for large- and medium-sieved cultivars. Thus, the seed index values obtained in this work could be an accurate estimate of what the finished product seed grades and percentage of fibre would be.

### *Effect of cultivar on the reproductive efficiency, fresh pod production, and pod quality*

The results of this study emphasise a great variation among cultivars in pod traits, allowing the classification of the cultivars into different groups. Some of the snap bean cultivars studied had yellow pods with some shade of green colour like the control cv. Oro del Rhin, but other cultivars had bright yellow pods, which is preferred for the fresh market because pale yellow is associated with over-mature beans. Excessive green colour in usable pod sizes is a problem, sometimes associated with very young pods, and the trend is to develop pods with an intense golden colour. Yellow pod colour is controlled by a single recessive gene (*y*), but it may be affected by a second gene (*arg*) and perhaps other modifiers (Currence 1931). Mullins and Coffey (1990) observed that the absence of a secondary green colour in the pods was more pronounced under warm and dry environmental conditions.

A group of snap bean cultivars had a much faster rate of pod development than other cultivars, as did the control cv. Dorada de Aragón, which in turn, produced higher fresh pod yield. The earliness of these old cultivars or landraces, which has been observed along with a high fresh pod yield and large-sieve pods, will allow breeders to optimise the level of earliness for each planting season, without reducing the yield, which is a key to the requirements of the snap bean crop.

## Conclusions

Large genotypic variation and interaction with planting season in pod characteristics were observed, which could be successfully used for adaptability improvement to specific environments. The differences observed between planting seasons were mainly due to a different vegetative growth cycle, pod production, and pod sieve. The identification of the variability and interaction with planting season is the first step to selecting parental lines with stability in pod traits to be used in breeding to obtain genotypes for different environments (which is critical in terms of adaptability). The results suggest that across environments the earliest maturing snap bean cultivars would have the highest fresh pod yields in late planting seasons while the latest maturing snap bean cultivars would have the highest fresh pod yields in early and normal planting seasons.

Early planting seasons will give higher pod yield and seed index or fibre development quality than late or normal planting seasons. Seed index tended to be lower in the late planting season under different environments. An early planting season would permit the optimisation of snap bean yield under humid environmental conditions. However, under conditions where planting is delayed due to factors such as unsuitable weather conditions, the highest fibre development quality might compensate for some of the pod yield losses. With increasing economic and social costs of irrigation, it is doubtful that growing snap beans under full irrigation in normal or summer plantings would be viable, and water and heat stresses could occur, leading to poorer yield.

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