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SUMMARY – Flower bud location and distribution were studied in 42 self-compatible almond selections from the Zaragoza breeding programme by counting all flower buds on four lateral branches of each selection. Total bud density varied from 0.11 to 0.66 bud/cm, whereas bud productivity ranged from 28.49 to 152.19 bud/cm^2. These values are relatively low for almond, but could be due to the young age of the trees. Two thirds of the selections showed higher bud density on the lateral branches than on the main branch. Shoot length and shoot thickness also affect bud density and productivity, thus indicating the advisable pruning for each selection according to flower position on the tree. The absence of clustering of the selections by their genealogical origin may indicate that bud density and productivity, traits showing low heritability, could already have been the object of previous selection of the clones studied.

Key words: Almond, *P. amygdalus* Batsch, bud density, growth habits, genealogical origin, cluster.

RESUME – *"La densité florale et le port de croissance comme critères de sélection chez l'amandier". La localisation et la distribution des bourgeons floraux ont été étudiées chez 42 sélections auto-compatibles d'amandier issues du programme d'amélioration génétique de l'amandier de Saragosse, en comptant l'ensemble des boutons floraux sur quatre rameaux latéraux de chaque sélection. La densité florale totale varie de 0,11 à 0,66 bourgeons/cm, alors que la floribondité varie de 28,49 à 152,19 bourgeons/cm*^{2}*. Ces valeurs sont considérées faibles pour l'amandier, ceci pourrait être attribué au jeune âge des arbres. Les deux tiers des sélections ont une plus grande densité florale sur les rameaux latéraux que sur le rameau principal, alors que l'autre tiers a présenté une densité florale élevée sur le rameau principal. La longueur et la vigueur des rameaux affectent la densité florale et la floribondité, ce qui implique le choix adéquat de la taille pour chaque clone suivant la position des fleurs sur l'arbre. L'absence de regroupement des sélections suivant leur origine généalogique pourrait indiquer que la densité florale et la floribondité, caractères montrant une faible héritabilité, pourraient avoir déjà été l'objet de sélection dans les clones étudiés.*

Mots-clés : *Amandier,* P. amygdalus *Batsch, densité florale, port de croissance, origine généalogique, cluster.*

Introduction

In the first selection steps in an almond breeding programme, several traits are taken into account, such as self compatibility, blooming time, tree morphology and fruit and kernel traits to select the genotypes approaching the objectives of the breeding programme. Once the best seedlings are selected, they must be grafted and planted in a study plot in order to characterize other important traits, such as the branching habit, the bloom density (Bernad and Socias i Company, 1998) and the tree structure (Kester and Asay, 1975). In fact, branching habit and tree structure define how a tree has to be pruned, because every growth habit requires a specific pruning technique (Royo *et al*., 1990) and, besides, pruning is one of the most expensive operations in almond growing. Bloom density is highly correlated with a high yield (Grasselly, 1972), which is considered another important breeding objective. Furthermore, bud density and tree structure are transmissible to offspring, and selection for these characters can be made. Our objective was thus to study these traits in several advanced selections of almond as a base for their further evaluation in the breeding screening.

Materials and methods

The 42 selections studied originated from crosses between four self-incompatible cultivars ('Desmayo Largueta', 'Marcona', 'Ferragnès' and 'Bertina') and four self-compatible genotypes of the Zaragoza breeding programme, the cultivars 'Moncayo', 'Guara' and 'Felisia' and selection A-10-6. These 42 genotypes were previously selected because of their self-compatibility, blooming time and good nut and kernel traits. They were grown at an evaluation plot grafted onto the almond × peach hybrid rootstock 'Garnem' (Gómez Aparisi *et al.*, 2001).

To determine bud density, four branches were selected around the trees with homogeneous form and position, but the different ramification of each variety made it impossible to fully homogenize the shape of all the branches. These were about 1.5 m above ground and 1 m long. Over two years all the secondary branches were noted and all the buds counted. The diameter at the base of the main branches was also measured to calculate the cross sectional area, thus allowing bud density to be expressed as the number of buds per unit length of shoots (Church and Williams, 1983) and per unit of cross section of the branch maintaining all branchings (Socias i Company, 1988). The buds were counted just before bloom, at stage B (Felipe, 1977), because flower buds were already clearly noticed. As the proportion of twin flowers varies according to the genotype, real flower density can change because flower buds were counted before their opening.

To study the possible factors influencing bud density, a multi-linear regression was applied taking bud density as dependent variable and as independent variables: total length of all shoots, total number of buds and the cross section of the branch sustaining all branchings. For the further characterization of these selections, these data were analysed by the principal component analysis (PCA) and the cluster analysis by SAS software (SAS Institute, 1988).

Results

Bud density

Large differences were observed for total bud density between the two years (Table 1 and 2). Only 5 of the 42 selections showed no significant differences between the two years. In 39 selections, bud density was higher in 2003 than in 2002. This increase could be due to the age of the trees, as they had not reached a mature age. In fact Kester and Asay (1975) reported that selection for this trait was only efficient after the fourth or fifth blooming season. On the other hand, selections G-1-38 and G-3-24 had a lower bud density in 2003 than in 2002. This decrease could be due to a higher sensitivity to alternance because in 2001 these selections showed the highest bud density. Only selection I-3-10 has maintained the same bud density in the two years.

The mean bud density of the two years, ranging from 0.11 to 0.60, is much lower than previously measured in other almond cultivars (Socias i Company, 1988) and selections (Bernad and Socias i Company, 1998). This difference could be due to the fact that the selections studied are much younger than those previously studied and to the high divergent weather conditions during the two years of this study.

As for bud density of the main branch, 10 selections showed significant differences between the two years. These differences could be due to the branch length, which could be different between the two years. For the lateral branches, large differences were found between the two years. Only 12 selections showed no significant differences between the two years. Both densities, however, were higher in 2003 than in 2002. This increase could be due to the larger number of lateral branches, increasing the bud density of the secondary shoots. This hypothesis was based in the significant positive correlation between bud density of the secondary shoots and the ramification index (0.40) and the significant negative correlation between this character and shoot length of the secondary shoots.

Bud productivity

Large differences for bud productivity were found between the two years (Tables 1 and 2). Only 4 of the 42 selections showed no significant differences between the two years. In 20 selections, bud productivity was much higher in 2003 than in 2002, and in the other selections was lower. These differences did not appear to be due to the variations in the cross sectional area between the two years, because all selections, except six, showed no significant differences for this trait between the two years. Thus, these differences could be explained by the increasing age of these young trees also increasing their ability to differentiate flower buds.

Table 1. Bud density and bud productivity of 42 almond selections in 2002

Selection	Cross section (cm^2)	Bud density (buds/cm)	Bud productivity (buds/cm^2)	Bud density of main branch (buds/cm)	Bud density of lateral branches (buds/cm)
G-1-1	1.25 NS	0.30***	140.9***	0.37 NS	0.07*
G-1-23	1.46 NS	0.22***	59.26***	0.16 NS	0.96***
G-1-27	0.95 NS	0.32 NS	129.9**	0.26 NS	0.55***
G-1-38	1.27**	0.55 NS	198.9*	0.14 NS	0.83 NS
G-1-41	1.14 NS	0.10***	54.16**	0.10 NS	0.16**
G-1-44	1.01 NS	0.03***	18.78**	0.01 NS	0.11**
G-1-58	1.15 NS	0.34***	145.2***	0.10 NS	0.57**
G-1-61	0.96 NS	0.30***	166.4*	0.31 NS	0.24**
G-1-64	0.90 NS	0.04***	31.00***	0.04*	0.05**
G-1-67	0.97 NS	0.20***	136.2*	0.16 NS	0.31 NS
G-2-1	0.69 NS	0.10***	59.10***	0.08***	0.17 NS
G-2-11	1.12 NS	0.37***	128.7**	0.36***	0.39*
G-2-2	1.18 NS	0.04***	18.52**	0.03***	0.12 NS
G-2-22	1.57 NS	0.13***	76.98***	0.08*	0.20*
G-2-23	1.07***	0.23*	125.6***	0.24 NS	0.22 NS
G-2-25	1.42***	0.07 NS	42.95 NS	0.10 NS	0.03**
G-2-26	1.01 NS	0.04***	24.94*	0.04 NS	0.07***
G-2-27	0.47 NS	0.08***	65.32 NS	0.06 NS	0.05 NS
G-2-7	0.95 NS	0.04***	27.12**	0.04*	0.06 NS
G-3-24	1.64 NS	0.38 NS	156.8***	0.33***	0.46*
G-3-28	1.20 NS	0.07***	34.79**	0.08 NS	0.04 NS
G-3-3	1.12 NS	0.25***	115.4**	0.21 NS	0.45*
G-3-4	0.85 NS	0.13***	80.49***	0.12 NS	0.13*
G-3-5	1.52 NS	0.07***	53.67***	0.03 NS	0.08***
G-3-65	0.84 NS	0.22***	122.4***	0.18 NS	0.35*
G-3-8	1.01 NS	0.09***	55.37***	0.04***	0.18***
G-4-10	1.15 NS	0.12***	57.81**	0.14 NS	0.05*
G-4-3	0.80 NS	0.28***	168.1*	0.35 NS	0.08*
G-5-18	0.98 NS	0.11***	59.91*	0.11 NS	0.11*
G-5-25	1.09 NS	0.21***	102.4**	0.21*	0.21**
G-6-14	1.01 NS	0.32***	118.5***	0.15 NS	0.51**
G-6-24	1.05 NS	0.06***	187.5***	0.05 NS	0.09**
G-6-39	0.73 NS	0.09***	51.44**	0.09 NS	0.10**
H-1-108	0.82 NS	0.04***	24.36**	0.01 NS	0.06 NS
H-3-37	1.23**	0.02***	10.55**	0.01 NS	0.03 NS
I-1-95	0.92 NS	0.30***	148.8 NS	0.20 NS	0.44***
I-2-12	1.12**	0.03***	16.05**	0.02 NS	0.05***
I-3-10	1.04**	0.41 NS	124.4***	0.14 NS	0.86 NS
I-3-11	1.54 NS	0.24***	137.4***	0.31**	0.09**
I-3-27	1.11 NS	0.18***	141.5**	0.11 NS	0.27***
I-3-65	0.72**	0.03*	30.40 NS	0.01 NS	0.06 NS
I-3-67	1.03 NS	0.02***	22.25***	0.01 NS	0.03***

NS, *, **, ***: non significant or significant at P = 0.05, 0.01 or 0.001 respectively, *t* test, in relation to year 2003.

Table 2. Bud density and bud productivity of 42 almond selections in 2003

Selection	Cross section (cm^2)	Bud density (buds/cm)	Bud productivity (buds/cm^2)	Bud density of main branch (buds/cm)	Bud density of lateral branches (buds/cm)
G-1-1	1.05	1.02	131.6	0.42	1.86
G-1-23	0.77	0.93	98.01	0.05	1.94
G-1-27	0.95	0.51	59.03	0.24	1.17
G-1-38	0.44	0.46	44.61	0.13	0.68
G-1-41	0.56	0.57	67.81	0.13	2.00
G-1-44	0.44	0.43	54.62	0.10	1.21
G-1-58	0.66	0.67	75.06	0.19	1.29
G-1-61	0.65	0.65	83.42	0.20	1.65
G-1-64	0.86	0.84	103.5	0.17	1.72
G-1-67	0.59	0.59	80.98	0.17	1.02
G-2-1	0.60	0.61	98.13	0.28	0.90
G-2-2	0.52	0.55	45.87	0.21	1.14
G-2-11	0.78	0.77	97.32	0.20	1.47
G-2-22	0.83	0.83	80.13	0.20	1.56
G-2-23	0.45	0.45	40.08	0.23	0.70
G-2-25	0.31	0.30	40.43	0.08	1.49
G-2-26	0.57	0.58	48.04	0.10	1.99
G-2-27	0.43	0.43	41.03	0.05	0.97
G-2-7	0.53	0.48	59.67	0.46	0.60
G-3-24	0.24	0.32	19.33	0.02	0.43
G-3-28	0.58	0.58	70.76	0.20	0.83
G-3-3	0.59	0.52	77.97	0.20	1.17
G-3-4	0.67	0.67	98.99	0.24	1.22
G-3-5	1.16	1.13	97.54	0.10	2.76
G-3-65	0.78	0.79	162.7	0.21	1.28
G-3-8	0.97	0.98	131.4	0.32	2.21
G-4-10	0.64	0.65	75.75	0.07	1.39
G-4-3	0.67	0.70	78.66	0.20	1.02
G-5-18	0.54	0.64	53.00	0.09	1.07
G-5-25	0.73	0.70	78.06	0.07	1.45
G-6-14	0.71	0.69	74.37	0.17	1.93
G-6-24	0.65	0.77	69.76	0.05	2.14
G-6-39	0.75	0.77	77.98	0.07	1.23
H-1-108	0.47	0.47	61.60	0.15	0.96
H-3-37	0.40	0.42	53.63	0.08	0.60
I-1-95	1.20	1.19	155.6	0.16	2.59
I-2-12	0.67	0.67	48.03	0.04	1.67
I-3-10	0.42	0.42	52.93	0.01	0.84
I-3-11	0.56	0.58	51.84	0.08	1.45
I-3-27	0.66	0.70	90.05	0.10	1.69
I-3-65	0.24	0.25	39.03	0.09	0.44
I-3-67	0.78	0.78	34.33	0.07	2.16

Variables affecting total bud density

The multilinear regression analysis showed that cross section, total branch length and total bud number influence bud density (Table 3). The cross section positively affects bud density probably by the improvement of the hydraulic conductivity of these branches and, consequently, by mineral nutrition favouring flower initiation (Bezzaouia, 1989). Total branch length negatively affects bud density, thus probably indicating that when resources are mostly allocated to shoot growth, less resources are available for bud differentiation, as reflected by the reduced presence of flower buds in vigorous branches (Bernad and Socias i Company, 1998), mainly in young plants.

Table 3. Variables affecting total bud density

Variable	Degrees of freedom	Parameter estimate	t value
Intercept	1	0.543	9.79 ***
Diameter	1	0.018	1.96 *
Total branch length	1	- 0.004	-12.18 ***
Ramification index	1	0.204	1.55 NS
Total bud number	1	0.007	19.76 ***

NS, *, ***: non significant or significant at P = 0.05 or 0.001 respectively, *t* test.

From the co-variance matrix of the means of all variables measured in 2003, PCA showed that the first three principal components retained explain 78.99% of the total variance (Table 4). Total bud number, bud number on lateral branches, total bud density and bud productivity had a high load in the first axis. Total branch length, lateral branches length, ramification index, cross section and bud density of lateral branches are strongly associated with the second principal component. And finally, bud density of main branch, bud number of main branch and diameter at the base of the main branch are associated with the third principal component (Table 5).

Table 4. Individual variance accounted for by the principal components retained

Axis	Eigenvalue	% of variance	% of cumulative variance
PC1	4.32	33.26	33.26
PC2	3.86	29.71	62.97
PC3	2.08	16.02	78.99

Table 5. Contribution of variables to the explanation of the first three principal components

Variables	PC1	PC2	PC3
Cross section (cm^2)	0.103	0.376	0.260
Diameter of main shoot (cm)	0.136	0.333	0.364
Total branch length (cm)	0.256	0.410	-0.054
Main shoot length (cm)	0.166	0.279	-0.005
Secondary shoot length (cm)	0.202	0.314	-0.042
Ramification index	-0.072	-0.313	0.211
Total bud number	0.468	-0.057	0.105
Bud number of the main shoot	0.272	0.010	-0.508
Bud number of the secondary shoots	0.430	-0.065	0.255
Total bud density (b/cm)	0.348	-0.319	0.163
Bud productivity (b/cm^2)	0.373	-0.243	-0.099
Bud density of the secondary shoots (b/cm)	0.159	-0.364	0.285
Bud density of the main shoot (b/cm)	0.257	-0.036	-0.520

The selections placed at the extreme positive part of the first principal component, had the higher values of total bud number, total bud density and bud productivity. Thus, selections G-1-1, G-1-64, G-

2-11, G-3-8, G-3-5, G-3-65 and I-1-95 showed the highest lateral branching, bud density and bud productivity (Fig. 1). Selections G-1-44, I-3-65, H-3-37, I-3-67 and G-2-25 have the lowest values of these characters.

As regards the second principal component, the selections placed in the positive part showed the longer lateral branches and their lower number, total bud density and bud density of the lateral branches. Selections G-2-23, G-2-27, G-3-24, G-3-4 showed low total bud density and bud density of the lateral branches and the highest lateral branches length, with the least lateral branches. Selections G-1-1, G-3-8, I-1-95, G-6-24 and I-3-67 have the highest bud density of the main branch, with the lower lateral branch length (Fig. 1).

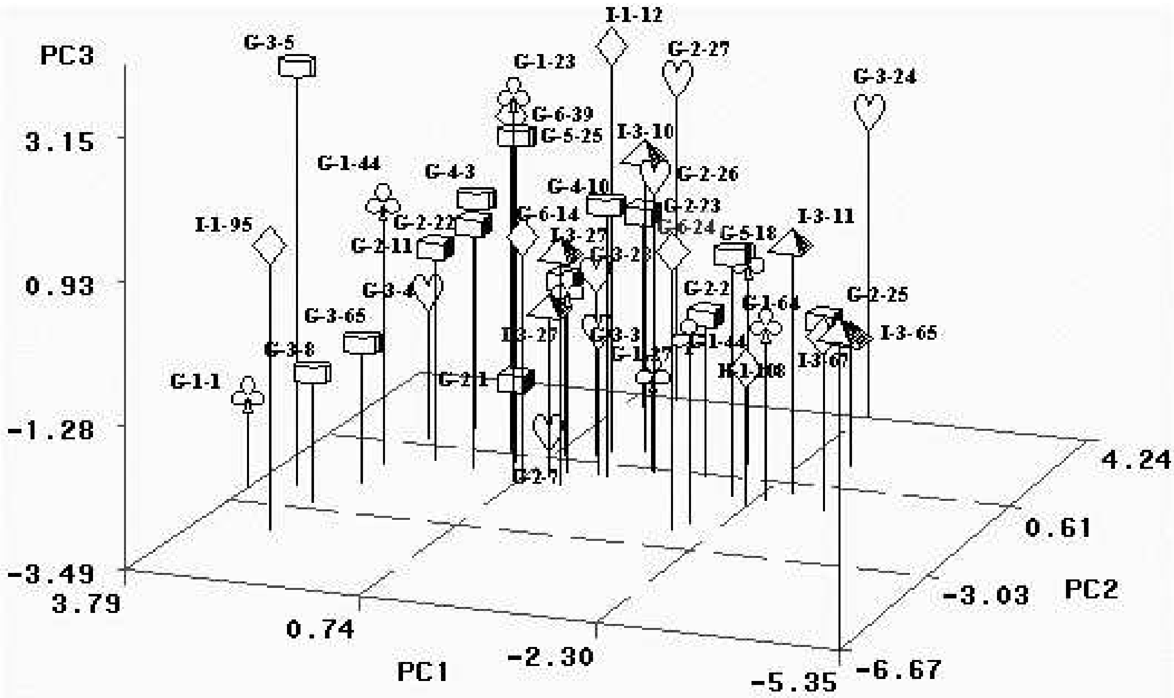

Fig. 1. Coordinate of the 42 selections on the three axes.

As for the third principal component, the selections positioned in the positive part showed a higher diameter at the base of the main branch and the lowest bud density of the main branch. So, selections G-1-23, G-3-5 and I-2-12 have the lowest bud density of the main branch and vigorous branches and selections G-2-1, G-2-7 and G-3-8 showed the highest bud density on the main branch.

The cluster analysis is a useful way to obtain the association between selections on basis of nearness criteria among objects. The resulting dendrogram (Fig. 2) showed two groups at a rescaled distance of 0.8. The first group contained 11.9% of all selections, characterised by the highest total bud density, bud productivity, bud density of the lateral branches and the lowest bud density of the main branch. Thus, bud density of this group is localised in short lateral branches. The second group was formed by 88.1% of the studied population, which is subdivided into two subgroups (Fig. 2). In the first subgroup, bud density is more important on the main branch than on the lateral branches, whereas in the second subgroup, bud density is more important in the lateral branches than in the main branch.

The differences in location of the bud density among the selections could indicate the morphologic differences in the growth habits of each selection, and reflects genotypic variations in the shoot morphology between selections, as described in peach (Kervella *et al.*, 1994). Based on this information, in terms of pruning, the elimination of longer or shorter shoots must be made regarding the localisation of bud density in relation to the growth habit and the tree structure of each selection. On the other hand, the results show that there was no apparent clustering of the selections by their genealogical origin.

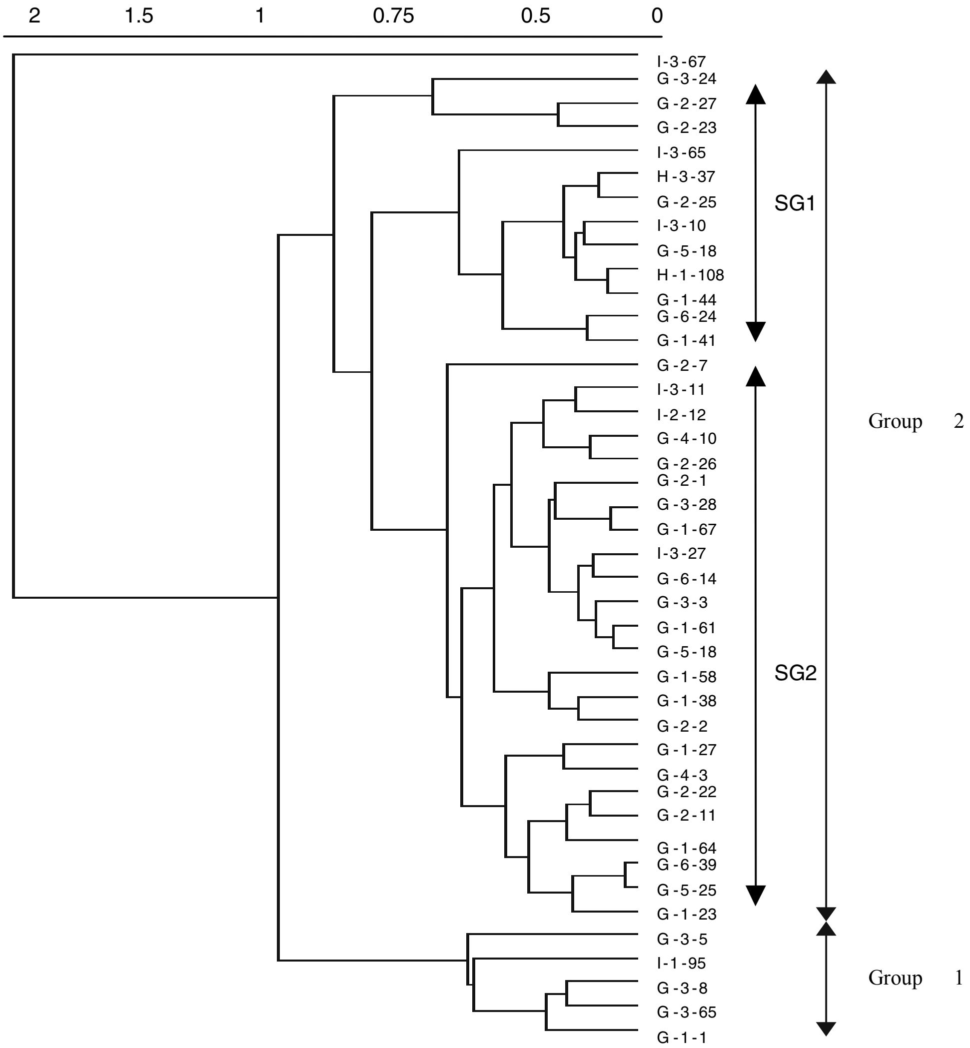

Fig. 2. Dendrogram obtained from an average linkage cluster analysis.

Discussion

The study of these 42 almond selections indicates that there is significant variability of bud density among them, allowing their selection on the basis of this trait, as already pointed out (Socias i Company, 1988). Bud density is very much influenced by the vigour, reflected by the growth habit and the ramification density. The distribution and the localisation of buds among the different types of shoots is different for each selection. Moreover, 28 of the 42 selections had a higher bud density on the lateral branches (mainly on short shoots) than on the main shoot, and 14 selections showed higher bud density on the main shoot, thus suggesting that the type of fructification must be taken into account to choose the type of most advisable pruning method, thus reducing pruning costs because this is one of the most expensive orchard operations. Easy training requires a compensated branching, which is considered an essential trait in an almond cultivar (Felipe and Socias i Company, 1985) and consisting of a reduction of main shoot growth with lateral branches evolving into fruiting spurs, and with weaker shoots with few buds (Bernad and Socias i Company, 1998). This type of growth reduces pruning but requires a continuous renewal on the tree.

Variation in bud density and growth habit between the two years could be due, mainly, to the young age of these selections, which still are in a developmental stage improving continuously their flower initiation ability, but also to the fact that bud density is a polygenic character (Kester and Asay,

1975) and weakly heritable (Sarvisé and Socias i Company, 2003). So, this trait may fluctuate according to the climatic conditions, and the weather conditions during the two years of this study were very divergent.

The absence of clustering of genotypes by their genealogical origin indicate that these selections did not appear to be related to their parents for bud density and growth habits, even though the differences observed reflect, in part, a genetic origin. These results agree with those of Bernad and Socias i Company (1998).

Although six selections were identified from the PCA analysis as having the highest bud density and bud productivity, the differences observed between the two years indicate that final selection can only be made when these traits become relatively stabilised at an increasing age of the trees of the evaluation plot.

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