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Selection for fruit removal force and related characteristics in olive breeding progenies

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Abstract. In the present work we discuss the possibility of breeding olives for suitability to mechanical harvesting. Variability in fruit removal force (FRF), and its correlation with fruit weight (FW) and yield were evaluated in reciprocal crosses of 'Arbequina', 'Frantoio' and 'Picual' cultivars. A wide range of variation was observed for FRF among the genotypes evaluated. A high correlation between FRF and FW was observed but not between FRF and yield. Analysis of variance showed significant differences among years but not among female genitors. Differences among genotypes, irrespective of their genitors, were also found, with the variance due to genotype being higher for FRF/FW than for FRF as dependent variable. Correlations of genotype data between years were significant for FRF/FW but not for FRF. The relatively low correlation values indicated that only some negative selection could be done on the basis of FRF/FW at the first stage of the breeding process, owing to the importance of the environmental variability. A more precise evaluation is needed during the successive stages of breeding, where several replicates per genotype are available.

Additional keywords: early selection, mechanical harvesting, *Olea europaea*.

Introduction

Harvesting labour represents up to 50–80% of the total production costs in olive (Tombesi 1990). Efficient mechanical harvesting equipment has been progressively used in olive to reduce labour input and cost (Antognozzi *et al*. 1990; Gil-Ribes and López-Giménez 2001). Chemical loosening agents have also been tested as fruit abscission promoters to facilitate harvesting (Barranco *et al*. 2002; Denney and Martin 1994; Hartmann *et al*. 1976).

Fruit removal force (FRF) has been seen as a critical factor of the suitability to mechanical harvesting (Antognozzi *et al*. 1990). This is affected by fruit maturation stage (Proietti *et al*. 2002), climatic conditions (Cavusoglu *et al*. 1990; Gil-Ribes and López-Giménez 2001) and cultivar attitude (Lavee *et al*. 1982). FRF has been used for evaluation of a cultivar's potential for mechanical harvesting (Antognozzi *et al*. 1990; Lavee *et al*. 1982; Preziosi and Tini 1990; Tous and Romero 1993; Tsatsarelis *et al*. 1984). Similarly, FRF has been used as a criterion for selecting the most interesting genotypes in breeding programs of other crops, such as coffee (Crisosto and Nagao 1991) or raspberry (Fejer and Spangelo 1973). Cultivar attitude to mechanical harvesting is also influenced by fruit weight (FW) (Lavee *et al*. 1982; Proietti *et al*. 2002), so that the FRF/FW ratio has been suggested as a good indicator of the suitability of olives for mechanical harvesting (Romero *et al*. 2002; Tsatsarelis *et al*. 1984).

The improvement of harvesting attitude has been considered one of the most important breeding objectives in olive, as most of the varieties currently cultivated are not adapted to modern intensively mechanised orchards (Fontanazza and Baldoni 1990; Lavee 1990). Most of the olive breeding programs currently being conducted are based on crossbreeding cultivars with known merit in vegetative growth traits, such as time to first flowering, fruit characters and yield components (Bellini 1992; Fontannazza *et al*. 1999; Pritsa *et al*. 2003). However, there is no information about FRF or harvesting attitude of olive breeding progenies in spite of the importance of these characters for modern olive cultivation.

The objectives of this work were to analyse the variability observed in olive progenies for FRF, to estimate genetic and environmental variances and their relation with FW and yield, and, therefore the possibility to select for suitability to mechanical harvesting in an olive breeding program.

Materials and methods

Plant material

Seedlings from reciprocal crosses including selfing made in Spring 1992 among 'Arbequina', 'Frantoio' and 'Picual' cultivars were used in this study. These genitors were chosen on the basis of their high productivity and oil content, earliness of bearing, fatty acid composition and their different geographical origin: 'Arbequina' from Catalonia, Spain; 'Frantoio' from Tuscany, Italy; and 'Picual' from

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Andalusia, Spain (Rallo 1995). Crosses were made by applying male pollen to female bagged branches and seedling growth was forced in greenhouse to shorten the juvenile period (Santos-Antunes *et al*. 1999). Seedlings were planted in open field in April 1994 at 1.5 by 3.5 m spacings and standard culture practices were followed in the orchard to ensure tree growth. The experiment was arranged according to a randomised complete block design with the 9 mentioned crosses, 4 blocks and 8 plants per replication.

Characters evaluated

Fruit was harvested at the same ripening index to avoid the influence of the ripening stage. The ripening index was based on the colour of the fruit (skin and flesh) scored on a scale from 0 to 7 (Frías *et al*. 1991). Fruits corresponding to category 4 (black skin and white flesh) were randomly sampled. The FRF of 50 fruits from each seedling was measured with a hand dynamometer (in grams, g) and fruits were then weighed to determine the average FW. After sampling, total yield and the percentage of fruit dropped per seedling were recorded. FRF and FW were only recorded in seedlings with the minimum amount of fruits required for these measurements (Table 1). Data were recorded over 3 consecutive years, from 1996 to 1998.

Data analysis

Correlation analysis between FRF and FW, total yield and percentage of fruit drop were carried out each year. A repeated measurement model was used to analyse data considering blocks and years as random effects and female genitors as fixed effects. Male effect was not analysed because there were suspicions of contamination in the crosses performed (De la Rosa *et al*. 2004). Analysis of variance was also performed by genotype (irrespective of the genitors) and year as random effects, including only the genotypes that were evaluated all 3 years to avoid unbalanced data. Analyses were performed using ANOVA and GLM procedures of SAS software (SAS Institute, Cary, NC).

Results and discussion

Progenies showed a wide range of variability for FRF, for all years and in all progenies independently of the female genitor, with values ranging from 134 to 546 g (Table 1). A similar degree of variability was previously obtained in cultivar evaluations (Lavee *et al*. 1982; Preziosi and Tini 1990; Tous and Romero 1993).

A significant positive correlation was found between the FRF and FW, this correlation being consistent over the 3 years evaluated (Table 2). Similar results have been previously reported in cultivar evaluations (Lavee *et al*. 1982; Romero *et al*. 2002; Tous and Romero 1993). However, this correlation is relatively low, indicating a possible selection of seedlings with low FRF and relatively high FW, since both parameters are important for the suitability to mechanical harvesting. For this reason, the FRF/FW ratio, which is proportional to the acceleration to be imposed for the fruit detachment, has been used for the classification of cultivars according to the ease of detachment (Antognozzi *et al*. 1990; Tous and Romero 1993; Tsatsarelis *et al*. 1984). FRF was negatively correlated with the percentage of fruit drop. This relationship was more evident in the first 2 years, because of unfavourable rainfall and wind conditions (data not shown). However, no clear correlation between FRF and yield was observed, although yield might have an indirect negative effect on FRF due to the negative correlation between yield and FW (León *et al*. 2004). Similar results were obtained from the evaluation of different cultivars (Lavee *et al*. 1982), where no correlation between the FRF and the yield or the oil content was observed either in different cultivars or within the same cultivar.

The analysis of variance showed no significant differences between female genitors, though such differences were observed among years (Table 3). The increase in average yield per tree over the 3 years (1.9, 2.2 and 7.2 kg in 1996, 1997 and 1998, respectively), particularly in 1998, led to a consequently lower FW (3.0, 3.7 and 2.3 g in 1996, 1997 and 1998, respectively) and FRF (Table 1). These data are consistent with the above

Table 1. Descriptive statistics for fruit removal force (g) by year and female genitor

Group	*n*	Mean	Min.	Max.	s.d.
		Year			
1996	122	328.8	146.8	546.0	87.0
1997	117	326.1	169.2	503.6	61.7
1998	222	244.6	134.0	474.8	69.0
		Female			
‘Arbequina’	205	294.6	143.2	488.0	77.0
‘Frantoio’	93	286.3	143.6	546.0	94.5
‘Picual’	163	279.5	134.0	544.8	84.1

Table 2. Correlation coefficients between fruit removal force and fruit weight, total yield and percentage of fruit drop in 1996, 1997 and 1998

*, P<0.05; **, P<0.01

	Fruit removal force (g)		
	1996	1997	1998
Fruit weight (g)	0.33**	0.29**	0.41**
Total yield (kg/tree)	–0.30**	0.24*	–0.01
Fruit drop (%)	–0.60**	–0.37**	–0.17*

Table 3. Analysis of variance for fruit removal force in a randomised complete block design repeated over 3 consecutive years

*, P<0.05; **, P<0.01

Source of variation	d.f.	SS	MS	*F*-value
Block	3	7404	2468	0.15
Female	2	40749	20374	1.24
Block × female	6	98243	16373	—
Year	2	530289	265144	88.51**
Block × year	6	17974	2993	—
Female × year	4	61383	15345	2.54
Block × female × year	12	72616	6051	—
Residual	210	847524	4035	—

Table 4. Analysis of variance for fruit removal force in seedlings evaluated over 3 consecutive years

*, *P*<0.05; **, *P*<0.01

Source of variation	d.f.	SS	MS	Variance (%)	*F*-value
Genotype	81	560434	6919	13.9	1.91**
Year	2	530289	265145	40.3	73.37**
Residual	162	585461	3614	45.8	—

mentioned relationships between these characters among genitors and indicate that the general suitability for mechanical harvesting could be very different from 1 year to the next.

Significant differences in FRF were found between genotypes and years (Table 4). Residual variance, which included genotype × year interactions and other random effects not accounted for, represented almost half of the total variance (45.8%). Variance due to yearly differences (40.3%)

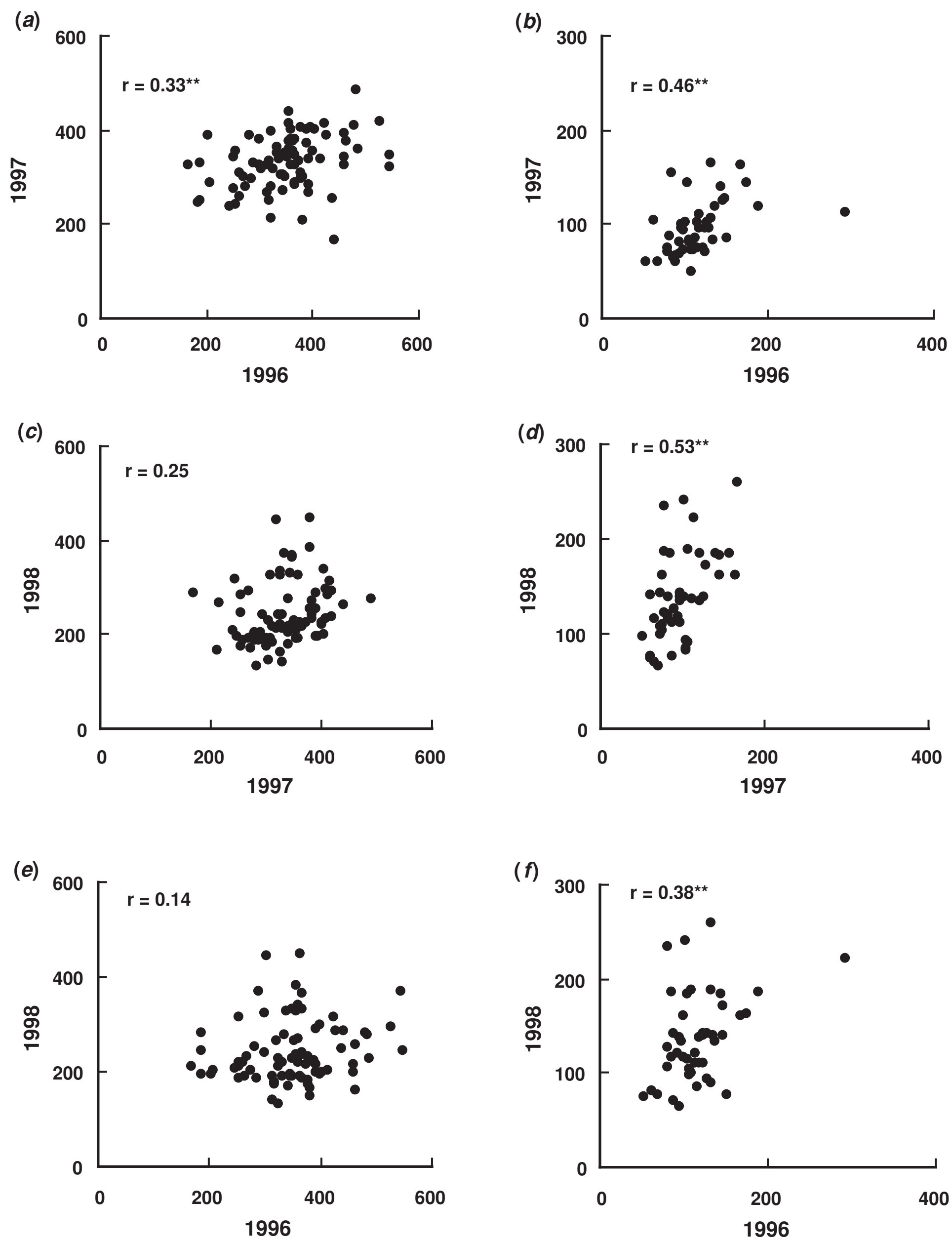

Figure 1. Scatter plots of correlation coefficients between the data obtained over 3 consecutive years for (*a*, *c*, *e*) fruit removal force (g) and (*b*, *d*, *f*) fruit removal force/fruit weight ratio. *, *P*<0.05; **, *P*<0.01.

was higher than genotype variance (13.9%). One of the major reasons for the variability in FRF could be attributed to the presence of fruits of different sizes on each tree, as the relationship between FW and FRF has also been demonstrated among fruit of different sizes within the same cultivar (Lavee *et al*. 1982). Considering the FRF/FW ratio, the different sources of variation (genotype, year and residual) accounted for 33, 22 and 45% of the total variability, respectively. In this case, genotype variance was higher than year variance, and residual variance remained the same as for FRF.

Additionally, low correlation coefficients were obtained for the FRF data between the first and second, second and third, and first and third years (Fig. 1). Correlation coefficients were higher and significant for the FRF/FW ratio in all 3 combinations. These results suggest that the values obtained the first year could not be reliable indicators for early selection of seedlings for these characters, although some negative selection could be made on the basis of the FRF/FW ratio data. Moreover, FRF cannot be the sole indicator for the response to mechanical harvesting. The geometry of the fruit and plant architecture can also affect the fruit detachment (Tombesi 1990; Tsatsarelis *et al*. 1984), although a high correlation between the FRF/FW ratio and mechanical harvesting efficiency, expressed as percentage of fruits dropped, has been reported (Antognozzi *et al*. 1990).

In fruit breeding programs repeated measurements on each genotype should be performed to avoid environmental variability and to achieve a high level of genetic discrimination. This could be done by measuring several samples from the same plant, different plants of the same genotype or the same plant during different years (Hansche 1983). The only measurement not performed in this work was recording data from several plants of the same genotype. However, in seedling populations of breeding programs only 1 tree is usually available for evaluation. Reports on other fruit breeding programs concluded that clonal replications should not be resorted to as a means of increasing precision, and it would be economically undesirable to replicate trees more than twice (Hansche *et al*. 1966; Iezzoni 1986; Yamada *et al*. 1993). Additionally, in olive breeding programs, where forced growth of seedlings in greenhouse is carried out to shorten the juvenile period, there is a strong limitation in the number of seedlings that can be raised yearly.

Conclusions

A wide range of variation has been obtained from the evaluation of FRF in olive progenies. This wide variability was observed irrespective of the genitor tested and no significant differences were obtained between the female genitors evaluated. The evaluation of seedlings for FRF could be difficult in the first stage of selection in olive breeding, because of the importance of the environmental variability. Measurements of FRF of pre-selected seedlings from several tree replications over several years and locations seem to be necessary to obtain a high level of genetic discrimination for this character.

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