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Associations among Morphological and Phonological Characters Representing Apricot Germplasm in Central Mexico

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Abstract. **Twenty variables were recorded on 15 apricot *(Prunus armeniaca* L.) genotypes differing in growth habit and blossom time to detect possible associations among morphological and phonological traits. The widest range of variability observed among phenotypes was for fruit size and factors associated with adaptation to local conditions, such as blossom season and yield potential as expressed by number of buds, flowers, and fruits per length of fruiting spurs. The most important morphological traits correlated with fruit weight were tree growth habit, apical and basal diameter of fruiting spurs, and bud and leaf size. Multivariate analysis allowed tree and variable grouping, which might encompass the basic criteria for apricot breeding programs in central México.**

More than 80% of the world apricot production is restricted to Mediterranean climates (Caccamisi et al., 1987; Westwood, 1975). Apricots could be cultivated commercially in other areas of the world to satisfy local demand. In the semiarid regions of México, apricots have been grown for more than two centuries and show a wide range of adaptation, but produce relatively small fruit.

With the exception of 'Canine' and 'San Castrese', which show a wider range of adaptation (C. Fideghelli, personal communication), apricot cultivars are highly specific in their ecological requirements (Bailey and Hough, 1975) and cannot be successfully cultivated away from their place of origin. Local breeding outside traditional growing regions should be encouraged to widen the distribution and cultivation of apricots (Bailey and Hough, 1975).

The early stages of any breeding program require germplasm collection and characterization. However, the information available on apricot descriptors includes mainly varieties from the European group (Couranjou, 1977; Sansavini et al., 1987). They are based on a wide range of characteristics, such as tree vigor and growth habit, leaf size and shape, productivity (Brooks and Olmo, 1972; Couranjou, 1977; Fideghelli and Monastra, 1977), disease resistance (Crossa-Raynaud, 1969; Guerriero and Watkins, 1984), fruit quality (Brooks and Olmo, 1972; Couranjou, 1977; Fideghelli and Monastra, 1977; Guerriero and Watkins, 1984; Monastra et al., 1984), and isozyrne differences (Byrne and Littleton, 1989).

More than three decades ago, Lapins et al. (1957) detected a high parent–offspring correlation for fruit size and flesh firmness, two of the most important traits related to fruit quality. However, with the exceptions of the report by Cociu (cited by Bailey and Hough, 1975) and the personal communication by C. Fideghelli and G. Della Strada (1991), very little information is available about simple associations between morphological traits and fruit quality in apricots.

The use of multivariate analysis has been used successfully in annual species to relate morphological and phonological traits with geographic and genetic origin in beans (Martin and Adams, 1987a, 1987b) and in perennial fruit species, such as sour cherries *(Prunus cerasus* L.) (Hilling and Iezzoni, 1988).

The main objective of this study was to describe the variability of several morphological and horticultural traits in apricot germplasm growing in central Mexico to detect possible associations among morphological traits and fruit size and variables that could be related to adaptation to local conditions.

Materials and Methods

Seed samples from orchards and village markets in the main apricot-growing regions in central Mexico were collected in 1984. In Spring 1985, resulting seedlings were planted at a semiarid location in northern Guanajuato, at a 2000-m elevation with 400 to 550 chilling hours. Seedling trees were grown using standard cultural practices.

The trees were classified according to growth habit and budbreak season during 1986–89. Fourteen seedling trees representing a wide range in growth habits and 'Canine' were evaluated for 20 traits in 1989 and 1990. The growth habit (GH) was evaluated visually using a scale, where 1 = bushy with a high degree of branching to 5 = erect and compact. The overall productivity (P) of the tree was rated, where 1 = very low to 5 = very high. Budbreak (BB) and harvest season (HS) ratings ranged from 1 = very early to 5 = very late. During bloom, the following measurements or counts were taken on 20 spurs per tree chosen randomly: the length of the spur (Ifs); basal and apical diameter of the spur (Bd and Ad, respectively); the size of flower buds (bd); the number of flowers per spur (fl); and the number of fruits per spur 8 weeks after full bloom. Ten fruiting branches were chosen randomly around the canopy at a height of 1.6 to 2.2 m, and the following measurements or counts were taken: branch diameter 5 cm above its base [it then

Abbreviations: Ad, apical diameter of spur; BB, budbreak season; bcsa, branch cross-sectional area; Bd, basal diameter of spur; bd, diameter of flower bud; Bd : Ad, basal diameter : apical diameter; fbn, number of flower buds per spur; fbn : Ifs, unopened flower buds per length of spur; fl, number of flowers per spur; fl : fbrr, flower : unopened flower buds; ff : Ifs, flowers per length of spur; fn, number of fruits per branch; fr : ifs, fruit per length of spur; fw, individual fruit weight; FW, weight of fruit per branch; FW : bcsa, yield efficiency; fw : sw, fruit : seed; GH, growth habit; HS, harvest season; 1, number of leaves per branch; la, individual leaf area; LA, total leaf area per branch; LA : FW, total leaf area : fruit weight; 1: fn, number of leaves : number of fruit; Ifs, length of spur; P, productivity; sw, individual seed weight.

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was converted to branch cross-sectional area (bcsa)]; number of leaves (l); and number (fn) and weight of fruits (FW). The leaf area (la) of 20 individual leaves per tree was measured using an electronic meter (Delta T-area measurement system; Decagon Devices, Pullman, Wash.). The individual fruit (fw) and seed weights (sw) of 20 fruits per tree were determined at harvest.

From these measurements or counts, nine more variables were calculated. These were: the ratio of Bd : Ad; the number of buds, flowers, and fruits per length of spur (fbn/ifs, fl/lfs, and fr/lfs × 100, respectively); the ratio of the number of flowers to the total number of buds per spur at blossom (fl/fbn); the ratio of 1: fn; the ratio of total leaf area (LA, average individual leaf area x number of leaves per branch) to FW (LA : FW); yield efficiency as FW to bcsa (FTV : bcsa); and the ratio of fw : SW.

Using mean values, associations among variables, as well as seedling grouping, were performed using Principal Component Analysis (Crisci and Lopez, 1983; Iezzoni and Pritts, 1991).

Results and Discussion

There was a wide range of variability among genotypes for most traits studied (Table 1), especially for those factors associated with yield efficiency, such as leaf area in relation to fruit produced (1 : fn, LA : FW, and FW : bcsa). This variation might be the result of different periods of natural and artificial selection under local conditions, as has been reported for other species (Montez, 1989). In addition to these variables, there was a group of traits that were slightly less variable but also associated with yield: fl : Ifs, fr : lfs, fl : fbn, fw, sw, and fw : sw. Some cultivar differences associated with yield components have also been reported for perennial species such as pears *(Pyrus communis* L.) (Kappel, 1990), blueberries *(Vaccinium corymbosum* L.) (Siefker and Hancock, 1986), and sour cherries (Chang et al., 1987).

With a similar degree of variability, there were three morphological (la, Ad, and Bd : Ad) and two phonological traits (BB and HS) that, with the other variables mentioned, could constitute the basis to define apricot tree groupings for selection purposes.

Finally, there was another set of factors that exhibited less variability among trees and included Ifs, bd, and fbn : ifs.

During the early stages of any breeding program, the main objective should be adaptability to local conditions (Bailey and Hough, 1975; Brauer, 1973). This is a highly complex factor, and in this study it was associated mainly with BB, fl : fbn, LA : FW, FW : bcsa, and fr : Ifs.

Early blooming genotypes, with early BB (< 2), are more susceptible to frosts, while those that bloom very late (BB = 5) are shy bearers under local conditions due to insufficient chilling accumulation. When winter chilling accumulation is enough to satisfy the requirements of a given phenotype, a high proportion of buds will be breaking (high fl : fbn), as has been reported for peach *[Prunus persica* (L.) Batsch] (Scalabrelli and Couvillon, 1986). In our study, fl: fbn was positively correlated with fl : lfs *(r-* = 0.91), fr : Ifs *(r* = 0.68), FW : bcsa *(r* = 0.66), and P *(r* = 0.66) (Table 2). However, it was negatively associated with some other important traits, such as GH *(r* = –0.67), Bd *(r* = –0.87), Ad *(r* = –0.82), la *(r* = –0.83), and fw *(r* = –0.86).

Once abroad basis for adaptation to local conditions has been established, some morphological factors related with tree structure become important to increase the efficiency of orchard management practices (Fideghelli et al., 1991; Scorza et al., 1986). In this study, I observed that a willowy growth habit, with values of GD < 2, demands more hand labor for pruning, spraying, and harvesting than the erect and more compact growth forms (GH = 4 and 5). Weak fruiting spurs with a narrow, pointed apex and values for Bd: Ad > 3 (Table 1) make pruning and harvesting operations more difficult and are associated with smaller fruit *(r* = 0.76 with fw).

More than 70 correlations among some of the 20 variables included on this study where higher than 0.6 and mainly involve GH, la, bd, Bd, Ad, and fw (Table 2). These associations could provide an efficient tool for selection purposes. For example, erect, compact growth habit (GH = 4 and 5), which is relatively easy to identify in the field, is strongly associated with other morphological traits, such as thicker fruiting spurs *(r* = 0.88 and *r* = 0.82 for Bd and Ad, respectively), larger leaves *(r* = 0.82, la), fruits *(r* = 0.79, fw), and seeds *(r* = 0.81, sw), and with more leaves per fruit *(r* = 0.61, 1 : fn). However, this trait is negatively correlated with some other important variables, such as the proportion of buds breaking and turning into flowers *(r* = 0.67, fl : fbn), fruits per meter of fruiting spur *(r* = 0.64, fr : Ifs), and P *(r* = – 0.46). This negative correlation means that, at least for this study, the more desirable tree structure for orchard management is less productive under this environment, possible due to a higher chilling requirement, as

Table 1.” Description of apricot germplasm growing in central Mexico.

Accession	GH	BB	Bd (mm)	Ad (mm)	Bd:Ad	lfs (cm)	bd (mm)	fbn:lfs (fbn:m)	fl:lfs (fl:m)	fl:fbn	fr:lfs (fr:m)	la (cm^2)	l:fn	LA:FW ($cm^2 \cdot g^{-1}$)	FW:bcsa ($g \cdot cm^{-2}$)	fw (g)	sw (g)	fw:sw	HS	P
I1-18	4	2	3.7	2.1	1.8	10.1	2.1	147	31.0	0.21	30.7	46.0	17.8	25.1	374	29.4	1.9	15.7	2	4
I10-2	3	2	2.9	0.9	3.0	13.9	1.8	96	43.3	0.45	40.5	20.3	8.5	12.5	285	13.4	1.1	12.4	3	4
II2-8	3	2	2.8	1.0	2.7	10.1	1.6	74	35.6	0.48	31.2	24.2	35.0	40.7	180	21.3	1.0	21.1	1	2
II3-11	4	5	3.6	2.6	2.3	13.3	1.9	169	32.0	0.21	15.0	43.3	35.0	14.6	157	18.2	1.8	10.2	1	2
II4-1	2	3	2.7	1.0	2.7	12.6	1.5	139	50.0	0.36	35.4	15.6	15.5	13.9	264	12.3	1.1	11.4	4	3
II4-4	3	2	2.3	0.9	2.4	10.3	1.7	146	68.0	0.47	65.8	20.2	7.4	4.1	462	12.2	1.4	9.2	2	5
II4-5	3	2	2.5	0.7	3.2	12.7	1.8	128	48.0	0.37	31.7	18.2	7.2	9.7	386	13.5	1.4	9.9	2	5
II7-3	1	2	2.1	0.6	3.7	9.5	1.5	161	59.6	0.37	43.2	14.3	6.0	14.9	230	5.8	0.5	12.5	4	4
II8-3	1	2	2.1	0.5	3.9	12.9	1.4	136	61.0	0.45	37.6	9.2	9.9	15.0	268	5.5	0.6	9.4	4	4
II8-9	2	3	2.2	0.7	3.0	12.8	1.7	108	47.0	0.43	45.4	10.5	13.1	15.1	153	15.3	1.1	13.4	4	4
III1-1	1	2	2.3	0.8	3.0	12.7	1.6	165	61.0	0.37	74.4	20.1	12.0	24.6	408	14.3	1.0	14.3	4	3
III1-5	5	5	4.8	2.2	2.1	10.2	2.6	137	15.0	0.11	14.4	42.1	32.0	31.6	195	42.5	2.1	20.3	2	1
III2-2	4	1	3.6	1.5	2.4	11.9	2.0	133	44.3	0.33	23.2	24.9	34.5	53.0	236	26.8	1.1	23.9	1	3
III6-6	4	3	3.0	1.0	3.0	17.1	1.9	103	37.0	0.36	31.3	31.4	52.9	42.2	175	28.2	1.7	16.9	3	4
Canino	3	3	3.6	1.8	2.0	12.5	1.9	126	25.0	0.20	21.2	35.6	45.2	58.8	151	37.6	2.2	17.2	2	4

Table 2. Correlation matrix among variables studied to describe apricot germplasm in central Mexico.

	GH	BB	Bd	Ad (mm)	Bd:Ad (mm)	lfs	bd (cm)	fbn:lfs (mm)	fl:lfs (fbn:m)	fl:fbn (fl:m)	fr:lfs (fr:m)	la (cm^2)	1:fn	LA:FW ($cm^2 \cdot g^{-1}$)	FW:bcsa ($g \cdot cm^{-2}$)	fw (g)	sw (g)	fw:sw	HS
BB	0.40																		
Bd	0.88	0.50																	
Ad	0.82	0.57	0.88																
Bd:Ad	−0.78	−0.28	−0.76	−0.83															
lfs	0.07	0.19	−0.10	−0.14	0.25														
bd	0.85	0.48	0.91	0.76	−0.70	−0.11													
fbn:lfs	0.07	0.25	0.05	0.28	−0.10	−0.17	0.07												
fl:lfs	−0.77	−0.52	−0.88	−0.77	0.64	−0.02	−0.77	0.24											
fl:fbn	0.67	−0.51	−0.87	−0.82	0.67	−0.03	−0.69	0.03	0.91										
fr:lfs	−0.64	−0.47	−0.70	−0.65	0.34	−0.11	−0.55	0.07	0.76	0.68									
la	0.82	−0.45	−0.86	0.92	−0.81	−0.07	0.77	0.20	−0.80	−0.83	−0.54								
l:fn	0.64	−0.46	0.63	0.56	−0.45	0.50	0.53	0.80	−0.60	−0.69	−0.60	0.61							
LA:FW	0.52	0.53	0.47	0.72	−0.41	0.20	0.27	0.25	−0.48	−0.57	−0.56	0.60	0.55						
FW:bcsa	−0.30	−0.47	−0.43	−0.36	0.07	−0.23	−0.18	0.28	0.62	0.66	0.72	−0.28	−0.57	−0.57					
fw	0.79	0.36	0.88	0.70	−0.76	−0.02	0.83	−0.14	−0.87	−0.86	−0.56	0.78	0.72	0.31	0.41				
sw	0.81	0.56	0.78	0.78	−0.80	0.13	0.78	0.04	−0.79	−0.74	−0.51	0.85	0.70	0.44	−0.23	0.84			
fw:sw	0.05	−0.11	0.59	0.33	−0.44	0.17	0.50	−0.35	−0.57	−0.58	−0.35	0.38	0.42	0.14	−0.44	0.72	0.27		
HS	−0.64	0.29	−0.51	−0.33	0.55	0.30	−0.56	0.30	0.39	0.28	0.29	−0.41	−0.22	0.04	−0.07	−0.61	−0.44	−0.61	
P	−0.46	−0.69	−0.72	−0.67	0.42	0.05	−0.58	−0.31	0.57	0.66	0.47	−0.51	−0.45	−0.53	0.49	−0.51	−0.38	−0.39	−0.09

Table3. Eigenvalues and propotion of the variability represented by the first four PCs in apricot germplasm grown in central Mexico.

PC	Eigenvalues	Proportion	Cumulative
1	11.06	0.55	0.55
2	2.64	0.13	0.61
3	2.00	0.10	0.79
4	1.27	0.06	0.85

Table 4. Correlations between original variables and the first four PCs representing apricot germplasm variability observed in central Mexico.

	PC			
Variables	1	2	3	4
GH	0.89	−0.19	0.02	0.22
BB	0.55	0.64	0.16	0.00
Bd	0.96	−0.10	0.07	−0.09
Ad	0.91	0.09	0.32	−0.05
Bd:Ad	−0.79	0.31	−0.34	−0.08
lfs	0.01	0.48	−0.47	0.67
bd	0.86	−0.22	0.18	0.05
fbn:lfs	0.02	−0.38	0.78	−0.02
fl:lfs	−0.92	0.02	0.21	0.07
fr:fbn	−0.91	−0.08	0.10	0.18
fr:lfs	−0.74	0.20	0.29	0.19
la	0.90	−0.04	0.24	0.11
l:fn	0.75	0.25	0.25	0.34
LA:FW	0.61	0.51	0.04	0.00
FW:bcsa	−0.53	−0.43	0.61	0.33
fw	0.90	−0.27	−0.11	0.05
sw	0.86	−0.05	0.14	0.39
fw:sw	0.57	−0.46	−0.39	−0.34
HS	−0.46	0.80	0.70	−0.18
P	−0.67	0.38	−0.16	−0.42

these trees generally tended to bloom very late in the season (with BB values of 4 and 5 in Table 1).

Thickness of fruiting spurs (Bd) was closely associated with bd (*r* = 0.91), la (*r* = 0.86), fw (*r* = 0.88), and sw (*r* = 0.78), but was generally less efficient, as it was correlated with a higher proportion of leaf tissue devoted to fruit production (r- = 0.63, 1 : fn). The large buds were found entrees with more erect growth habit and thicker fruiting spurs with larger leaves, fruits, and seeds, which are generally less efficient. When fl : fbn was high, the number of flowers (*r* = 0.91, fl : ifs) and fruits (*r* = 0.68, fr : Ifs) per meter of fruiting spurs was also high, as was FW :bcsa (*r* = 0.66) and P (*r* = 0.66) . However, the high fl : fbn ratio was also associated with smaller leaves (*r* = –0.83, la), fruits (*r* = –0.86, fw), and seeds (*r* = –0.74, sw); a less erect GH (*r*-= –0.67); and pointed fruiting spurs (*r* = –0.82, Ad).

When all variables were integrated by principal components (PC), 85% of the variability observed was explained by the first four PC (Tables 3 and 4). PC1 represents mainly nine variables (GH, Bd, Ad, bd, LA, fw, sw, fr : ifs, and fl : fbn), while BB and HS were the most important traits integrated by PC2. The first six variables listed on PC1 integrate a compact group when PC1 and PC2 are plotted on a bidimensional plant (Fig. 1). Bud density (fbn : ifs) and production efficiency (FW: bcsa) become important for PC3, and lfs along with P are represented by PC4. Some traits, such as bd, that had a lower range of variability among phenotypes now become important.

Some other closely associated variables that constitute couples on the left side along the PC1 are P and FW : bcsa and fl : fbn and fr: Ifs. These variables reflect more closely the degree of adaptation to local conditions.

Tree group formation based on the 20 variables included in this study could provide an efficient selection tool for apricot breeding programs outside traditional growing regions. For example, 117-3, 118-3, and 1111-1 constitute a group when they are plotted on a tridimensional graph (Fig. 2). These seedlings were included under type 1 GH and, even though productive, should be discarded, as they have smaller fruits and spurs with dry, pointed apices that resemble spines and demand more labor.

Natural and artificial selection includes some factors that have been important for adaptation to local conditions and here were associated with fl : fbn values that are higher than 0.2 and flower densities of at least 30 fl : lfs (Table 1).

Trees with relatively large fruit, which constitute one of the main objectives of this breeding program, integrate a separate group toward the right side of the graph (Fig. 2). Hybridization between highly productive selections and those with larger fruit is expected to produce a wide range of phenotypes that will be the basis for selection.

Some of the associations reported here might not be as high

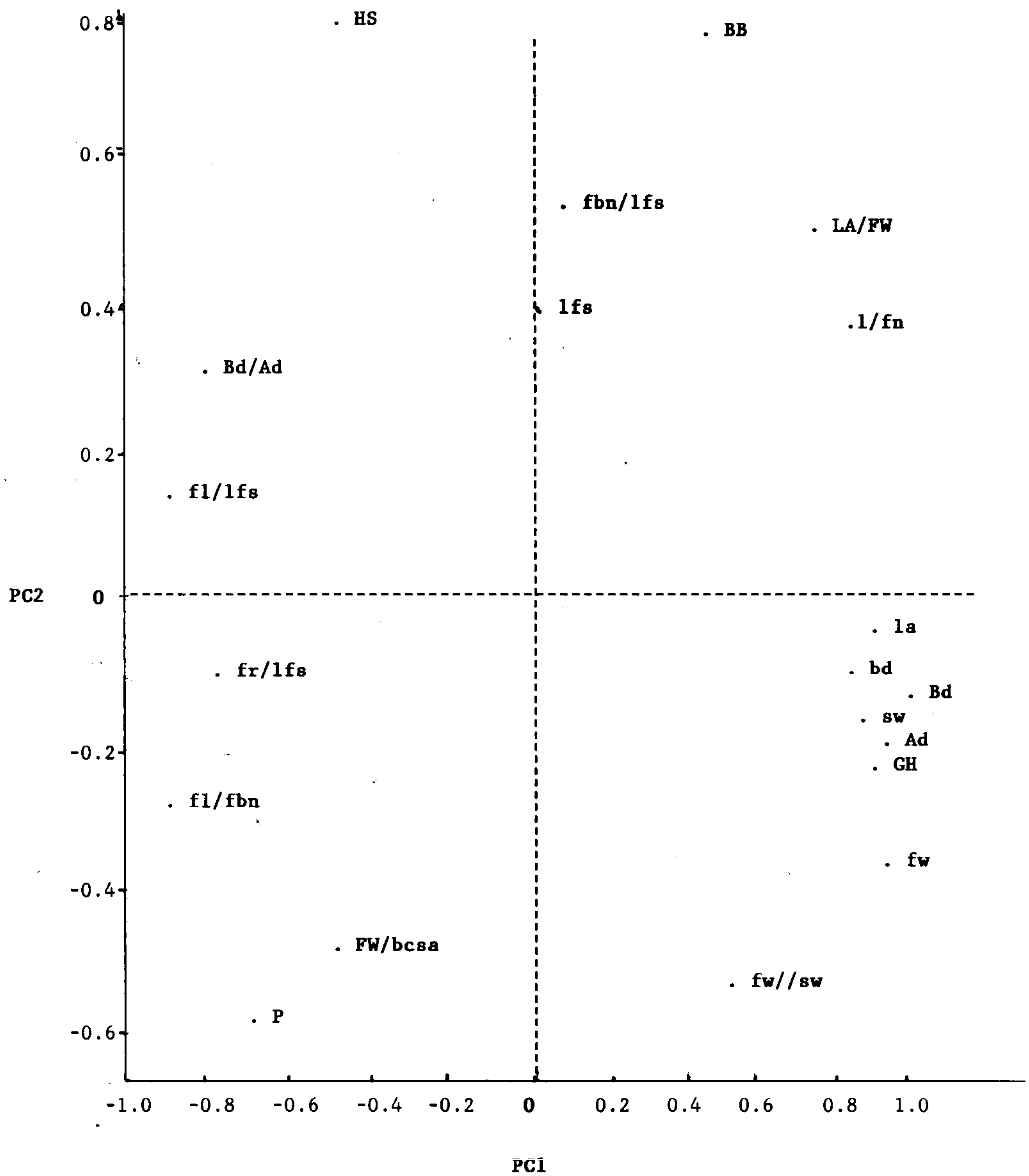

Fig. 1. Degree of association among variables of apricot germplasm as given by the relationship between PC1 and 2 for seedlings grown in Guanajuato, México.

during later stages of this or other breeding programs, when range of phenotypes is narrower. Nevertheless, intermittent characterization of apricot germplasm could detect some interesting correlations among some other traits, especially if they are related with several aspects of fruit quality, such as color, firmness, and flavor.

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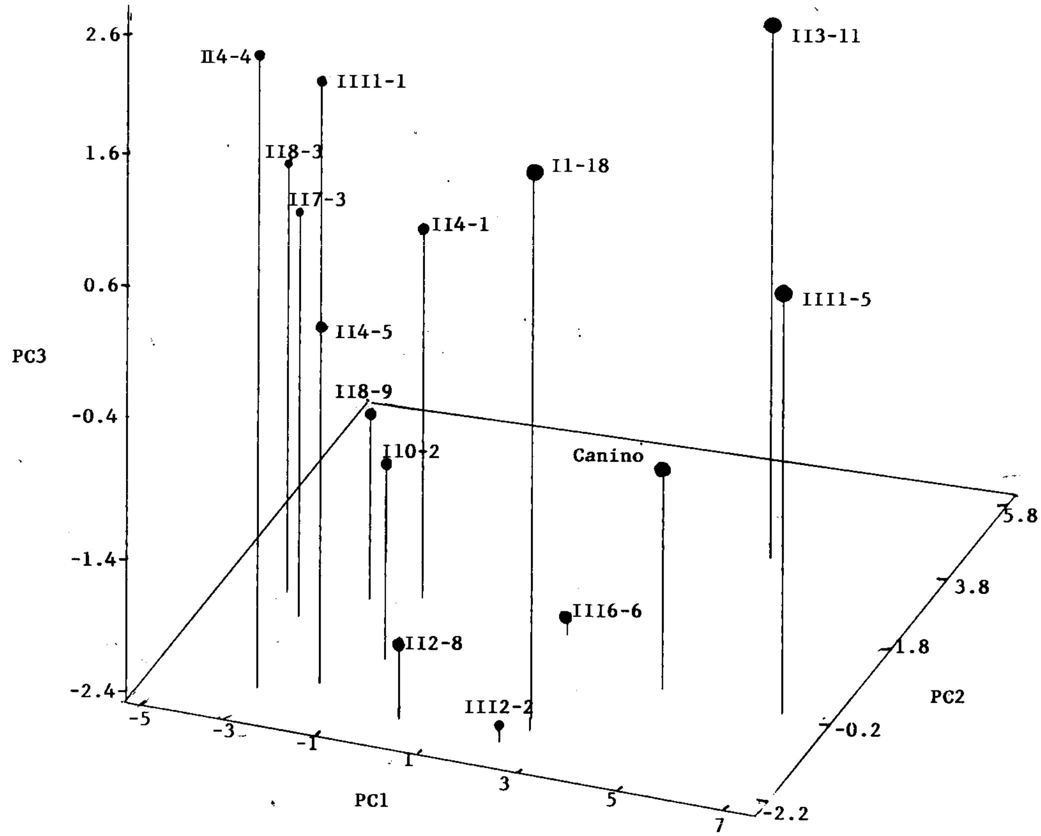

Fig. 2. Grouping of apricot tree genotypes grown in Guanajuato, México, as given by the relationship between PC 1, 2, and 3. Circle size reflects fruit weight.

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