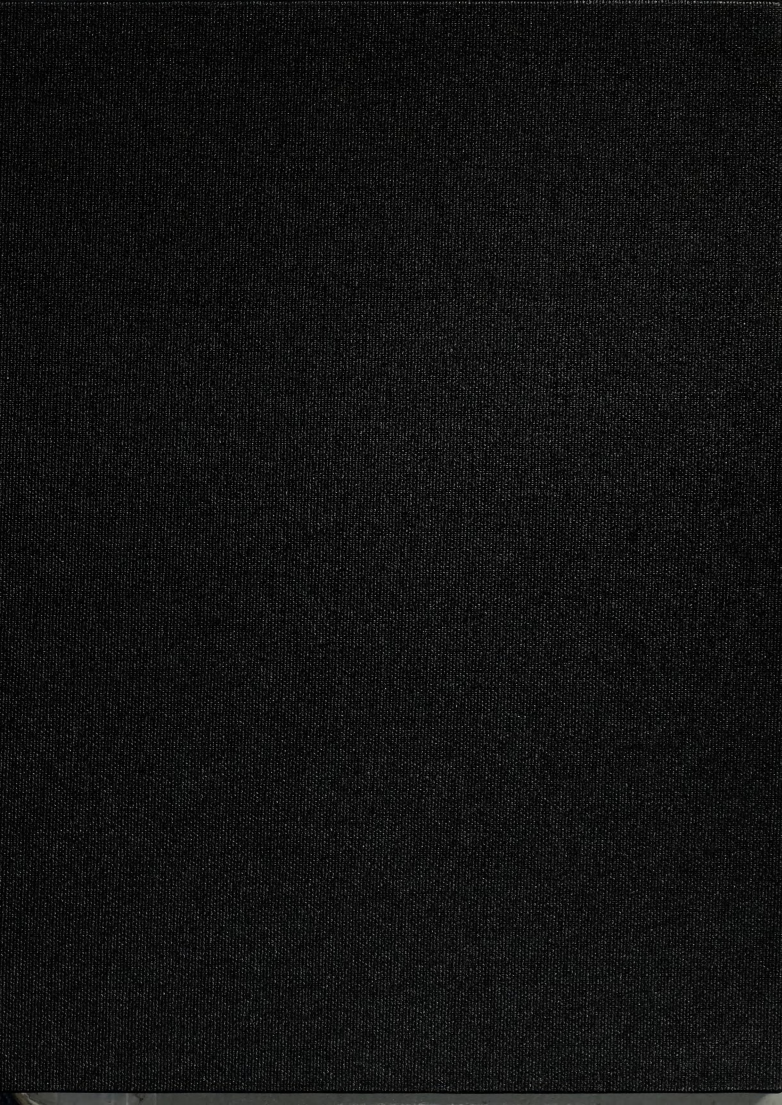






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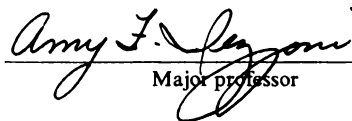
Self-Incompatibility in Sour Cherry (Prunus cerasus L.)
and Inbreeding and Multivariate Relationships Among
Almond (Prunus dulcis (Miller) D.A. Webb) Cultivars

presented by

ALI LANSARI

has been accepted towards fulfillment
of the requirements for

Ph.D degree in Horticulture


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SELF-INCOMPATIBILITY
IN SOUR CHERRY (Prunus cerasus L.)
and
INBREEDING AND MULTIVARIATE RELATIONSHIPS AMONG
ALMOND (Prunus dulcis (Miller) D.A. Webb) CULTIVARS

BY

Ali Lansari

A DISSERTATION

Submitted to
Michigan State University
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1993

ABSTRACT

SELF-INCOMPATIBILITY IN SOUR CHERRY (Prunus cerasus L.) and INBREEDING AND MULTIVARIATE RELATIONSHIPS AMONG ALMOND (Prunus dulcis (Miller) D.A. Webb) CULTIVARS

BY

ALI LANSARI

Self-incompatibility was investigated in sour cherry (Prunus cerasus L.) by examining pollen growth in the pistil using ultraviolet (UV) fluorescence microscopy following self- and cross-pollination. The sour cherry cultivars 'Tschernokorka' and 'Crisana' exhibit pollen tube inhibition in the style characteristic of gametophytic self-incompatibility. 'Meteor' and 'Montmorency' appear to be partially self-incompatible with few self-pollen tubes reaching the ovary. Pollen growth rate is different according to the male parent and to the receptive pistil.

Pedigrees of 124 almond, Prunus dulcis (Miller) D.A. Webb, cultivars from U.S., Russia, Israel, France, and Spain were used to calculate: 1) the inbreeding coefficients of these cultivars, 2) the genetic coancestries among these cultivars, and 3) the genetic contribution of founding clones to these cultivars. The recurrent use of 4 selections as parents in the U.S. breeding programs has resulted in a mean inbreeding coefficient (F) within the U.S. germplasm collection of 0.022. In France, a single cultivar, 'Ferralise', has an inbreeding

value of $F = 0.250$, while cultivars of other almond producing countries are noninbred ($F=0$). Due to the use of common parents, the American, Russian, and Israeli cultivars share coancestry, while coancestries also exist between French and Spanish almond germplasm. Cultivars of known parentage, including those released through breeding programs, in the U.S., Russia, Israel, France, and Spain trace back respectively to 9, 8, 3, 4, and 3 founding clones. Almond breeding programs might, in the future, narrow the almond germplasm genetic base thereby limiting genetic gain.

Principal component analysis (PCA) was used to quantify morphological variation among eighty one selected Moroccan clones and introduced cultivars. Moroccan selections tended to be characterized by small leaves in comparison to foreign cultivars. Variability for nut and kernel traits was identified, and along with several clones which have very good nut and kernel characteristics. There is, however, some evidence that the fruiting potential of Moroccan selections remains limited, even though some of them had a large number of spurs. No evidence was found of separate ecotypes existing in the southern Moroccan almond populations.

DEDICATION

To my father and mother who always gave me love and support, and whom I always cherished and loved.

To my father who taught me a lot about life.

To my wife, Fouzia, who has always been beside me, and who always provided me with the love and support I needed throughout the years of our marriage. She always left everything behind to help and encourage me to complete this work.

To my cherished children, Kawtar and Soufiane, who always brighten my dark moments with their smiles and laughs. I love them very much.

To my brothers, Aziz and Mohammed, and my sisters, Houria, Sabah, Zoulikha, Bouchra, and Soumia, for their understanding and love.

To all my friends.

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INTRODUCTION

Self-incompatibility ensures outcrossing which promotes heterozygosity, permitting a greater capacity to adapt to different environments. This may result in a wider species range. Self-compatibility can develop through evolution, either by mutation of self-incompatibility alleles to self-compatible ones, or by interspecific hybridization of self-incompatible and self-compatible species, giving rise to self-compatible genotypes within a species or to a new self-compatible species. Prunus species are either self-compatible or self-incompatible. The tetraploid sour cherry (Prunus cerasus L.) is thought to have resulted from hybridization between sweet cherry (P. avium L.), which is a self-incompatible diploid, and the tetraploid ground cherry (P. fruticosa Pall.). Sour cherry is known to be self-compatible, but cultivars with varying degrees of self-incompatibility have been reported. The objective of the work described in chapter 1 was to characterize self-incompatibility in sour cherry. This was achieved by examining pollen tube growth in the pistil using ultra violet fluorescence microscopy, in four sour cherry cultivars and several hybrids of self-compatible sour cherry cultivars.

Under certain environmental conditions and in the presence of natural barriers, gene flow can be restricted and species can be isolated, giving rise to identifiable ecotypes. Under

human and natural selection forces in different countries, almond ecotypes have evolved and developed characteristic traits (i.e., self-compatibility in almond (Prunus dulcis (Miller) D.A. Webb) Puglia ecotypes in Italy, soft shell types in California). Fruit breeders select superior genotypes of almond from available ecotypes, and use them as commercial cultivars and as gene sources for cultivar improvement. Extensive use of common parents in breeding programs reduces genetic diversity and increases inbreeding and coancestry relationships among released cultivars. However, in Morocco, almond, which is an outcrossing Prunus species, is mostly propagated by seeds and is grown under various environmental conditions. These conditions increase genetic diversity and may result in the development of characterized ecotypes.

In Chapter 2, the level of inbreeding and coancestry relationships among almond cultivars from different almond producing countries was determined. In Chapter 3, morphological variation among Moroccan selections and introduced cultivars was studied using multivariate statistics.

CHAPTER I

A PRELIMINARY ANALYSIS OF SELF-INCOMPATIBILITY IN SOUR CHERRY (Prunus cerasus L.)

SUMMARY:

Self-incompatibility was investigated in sour cherry (Prunus cerasus L.) by examining pollen tube growth in the pistil using ultraviolet (UV) fluorescence microscopy following self- and cross-pollination. The sour cherry cultivars 'Tschernokorka' and 'Crisana' exhibit pollen tube inhibition in the style characteristic of gametophytic self-incompatibility. 'Meteor' and 'Montmorency' appear to be partially self-incompatible since some but not many self-pollen tubes reach the ovary. Pollen germination rates were different according to the pollen source and the receptive pistil.

INTRODUCTION:

Self-incompatibility in Prunus is widespread. Most commercial almond cultivars (P. dulcis Miller) (Socias I Company et al., 1976; Crossa-Raynaud and Grasselly, 1985) and sweet cherry cultivars (P. avium L.) (Crane and Lawrence, 1929; Crane and Brown, 1937; Way, 1967) exhibit gametophytic self-incompatibility and cross-incompatible groups have been identified. In plums (P. domestica), the expression of self-incompatibility is more complex. Plums can be self-compatible, self-incompatible, or partially self-compatible, and only a few examples of

cross-incompatibility have been reported (Crane and Lawrence, 1929; Suranyi, 1978).

Although the tetraploid sour cherry is generally considered self-compatible, self-incompatible sour cherry cultivars do exist (Lech and Tylus, 1983; Redalen, 1984a, 1984b). These self-incompatible cultivars generally represent old landrace cultivars which are being replaced in commercial production by self-compatible types. Besides the two classifications of self-compatible and self-incompatible, Redalen (1984b) describes a partially self-incompatible class in sour cherry, which he defined as having 1.5% to 15% fruit set.

The sour cherry industry in the United States is a monoculture of the cultivar 'Montmorency'. Beginning in 1983, sour cherry germplasm, including some self-incompatible cultivars, was imported into the United States from Europe for use in sour cherry breeding. The objectives of this study were to evaluate pollen tube growth in sour cherry cultivars previously reported to be self-compatible or self-incompatible. Pollen tube growth in the pistil was examined using ultraviolet (UV) fluorescence microscopy.

MATERIALS AND METHODS:

Plant material: A diallel cross was made among four sour cherry cultivars: 'Tschernokorka', 'Crisana', 'Meteor', and

'Montmorency'. 'Tschernokorka' and 'Crisana' are reportedly self-incompatible (Redalen, 1984a, 1984b). Two sweet cherry cultivars, 'Emperor Francis' and 'Schmidt' were also included for comparison.

All the plant material tested was planted at the Clarksville Horticultural Experimental Station, Clarksville, Michigan, U.S.A.

Pollination and evaluation: Pollen was collected from cut branches forced indoors at room temperature. Pollen viability was tested by the method of Werner and Chang (1981) using 3(4-dimethylthiazolyl-2)2,5-diphenyl tetrazolium bromide (MTT) (Sigma, St. Louis, MO.) as the pollen staining agent, because of its high correlation with pollen germination. A drop of a solution of 100 mg of MTT in 5 ml of 10% sucrose solution was placed on the microscope slide, the pollen dusted onto the surface, and a coverslip added. Counts were made one hour later for the development of a satisfactory red color. Pollen grains that stained red or dark red were considered as viable, pollen staining light red were considered of reduced viability, and colorless pollen grains were non viable.

Flowers on branches in the field selected for crossing were emasculated at the balloon stage, all other flowers being removed. Emasculated flowers were hand pollinated when receptive. 'Schmidt' and 'Emperor Francis' were pollinated May 13, 1989, 'Montmorency', 'Crisana', and 'Tschernokorka' were

pollinated May 14, and 'Meteor' was pollinated May 16. The minimum and maximum temperatures for May 13 through May 19 were 9-15°C, 10-20°C, 10-21°C, 10-25°C, 11-29°C, 14-27°C, and 17-22°C, respectively. Ten pollinated pistils per cross were collected 24, 48, and 72 hours after pollination and fixed in Farmer's fixative solution (glacial acetic acid:ethanol, 1:2, v/v).

The pistils were prepared for fluorescent microscopy with a modification of Martin's technique (1959). They were thoroughly washed under running tap water and autoclaved for 10 minutes in 1% sodium sulfite (Merck, Cherry Hill, N.J.) solution to soften the tissues. After removal of the epidermis, the pistils were soaked in 0.1% aniline blue (Sigma, St. Louis, MO.) solution at pH 8.5 for 10 to 15 minutes. Pollen tubes were observed by UV fluorescent light microscopy using an Olympus BH-2 microscope, with A 10 PL of 0.25 aperture, and A40 PL of 0.65 aperture objectives. The exciter filters used were UGL for ultraviolet excitation, and BP490B for blue excitation. Aniline blue in alkaline solution will fluoresce under UV light when it is complexed with polysaccharide which is present in callose plugs (Stone et al., 1984).

Pollen-pistil incompatibility was defined as no pollen tubes reaching the ovule on all pistils observed, while compatibility was considered to exist when at least one observed pistil had pollen tubes reaching the ovule.

Pollen tube growth was determined by the distance pollen tubes had penetrated into the upper 1/4, upper 1/3, lower 1/3, lower 1/4 of the style, or reached the ovule. Data is represented as the mean percentage of total style length travelled by pollen tubes of 10 pistils per cross.

RESULTS:

All cultivars tested were cross compatible (Table 1).

'Tschernokorka' and 'Crisana' sour cherries and the sweet cherry cultivars were self-incompatible; no pollen tubes reached the ovule in any of the 10 pistils observed. 'Meteor' and 'Montmorency' were scored; in these two groups, at least 50% of the pistils had pollen tubes reaching the ovule (Table 1). However, not all the pistils observed had pollen tubes that reached the ovule 72 hours after pollination (Fig. 2C and D). Self-incompatibility in 'Tschernokorka' and 'Crisana' was characterized by inhibition of pollen tube growth in the stylar tissue (Fig. 1). Self-pollen of 'Crisana' and 'Tschernokorka' initially grew as fast as foreign sour cherry pollen; however, pollen tube growth was reduced 48 hours after pollination and stopped approximately half way down the styles 72 hours after pollination (Fig. 2A and B). In the incompatible sour cherry pollinations, pollen tube branching, bursting or growth reversal were observed. The swelling of pollen tube tips, which is usually associated with

Table 1. Self-incompatibility (-) and self-compatibility (+) among six cherry cultivars based upon controlled crosses.

Pistil	Pollen					
	EF	Sch	Tsch	Cris	Met	Mont
Emperor Francis	-	+	+	+	+	+
Schmidt	+	-	+	+	+	+
Tschernokorka	+	+	-	+	+	+
Crisana	+	+	+	-	+	+
Meteor	+	+	+	+	+	+
Montmorency	+	+	+	+	+	+

(-) indicates that pollen tube growth in all pistils observed was arrested in the stylar tissues.

(+) indicates that more than 50% of the pistils observed had pollen tubes reaching the ovule.

Fig. 1. Pollen tube growth in sour cherry pistils 72 hours after pollination: (left) 'Crisana' self-pollinated, (middle) 'Meteor' self-pollinated, and (right) 'Crisana' x 'Meteor'. The pistils were purposely curved before the photographs were taken.

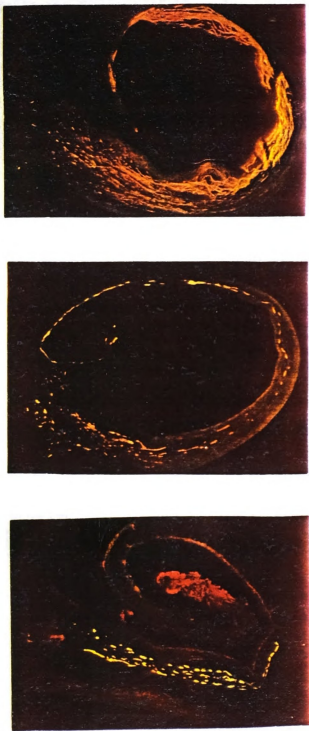
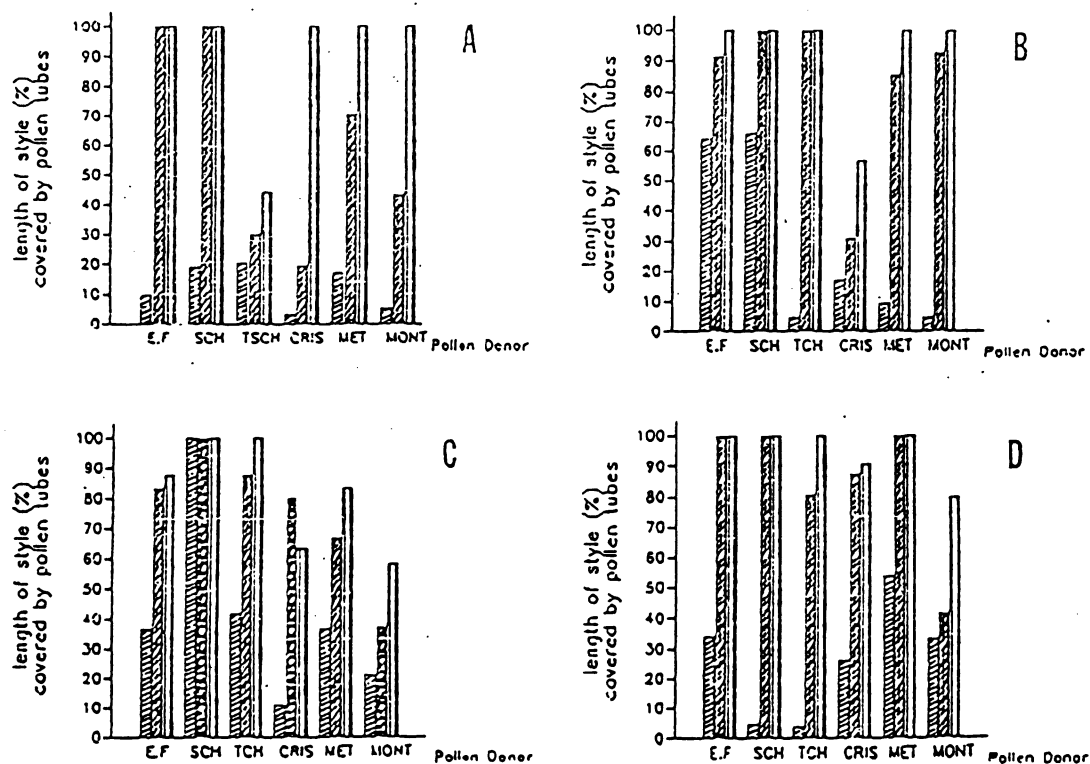


Fig. 2. Mean of the percentage of style length of (A) 'Tschernokorka', (B) 'Crisana', (C) 'Meteor', and (D) 'Montmorency', covered by pollen tubes 24, 48, and 72 hours after pollination. Values represent the mean of 10 styles.

▨ 24 h, ▤ 48 h, □ 72 h after pollination.



gametophytic incompatibility, was observed in the sweet cherry cultivars but not in the self-incompatible sour cherry cultivars. 'Crisana' pollen grew the best on 'Tschernokorka' pistils (Fig.2), while all cross pollen types grew successfully on 'Crisana' pistils (Fig. 2C).

'Montmorency' and 'Meteor' were self-compatible with self-pollen successfully reaching the ovule. However, for 'Montmorency', self-pollen grew more slowly than foreign pollen. Effectively, the mean percentage of total style length travelled by pollen tubes 72 hours after pollination was 80%, since not all the pistils observed had pollen tubes that reached the ovule (Fig. 2D). In the 'Meteor' styles, self-pollen and pollen of 'Crisana' and 'Montmorency' generally grew more slowly, with mean values of 80%, 65%, and 60% respectively, as compared to pollen of the two sweet cherry cultivars and 'Tschernokorka'sour cherry (Fig. 2C), and as compared to the styles of the other sour cherry cultivars (Fig. 2). Additionally, for both 'Montmorency' and 'Meteor', very few self-pollen tubes reached the last one third of the style (Fig. 1), many of them being inhibited along the transmitting tissue in a pattern more variable than that exhibited for out-cross pollinations (Fig. 1C). This could not be attributed to pollen quality, since the 'Montmorency' and 'Meteor' pollen grew successfully in the styles of other cultivars. It was noted that sweet cherry pollen generally

grew faster than sour cherry pollen in sour cherry styles (Fig. 2A-D).

CONCLUSION:

Self-incompatibility in sour cherry is characterized by inhibition of pollen tube growth in the style suggesting gametophytic self-incompatibility as reported for other self-incompatible Prunus species. In the incompatible pollinations, the pollen tubes initially penetrated into the style and grew normally; however, growth stopped when the pollen tubes were approximately half way down the style. Our results are contrary to those of Lech and Tylus (1983) who observed no pollen tube growth beyond the stigma for the sour cherry cultivar 'Koroser', presumably synonymous to the Romanian cultivar 'Crisana'.

Redalen (1984b) classified 'Montmorency' and 'Meteor' as partially self-incompatible based on low fruit set following self-pollinations. 'Montmorency' and 'Meteor' did exhibit inhibition of a large percentage of self-pollen in the style. This observation could represent the partial self-incompatibility described by Redalen (1984a, 1984b).

Pollen growth was different according to the donor parent and to the female parent. In general, 'Emperor Francis' and 'Schmidt' sweet cherry pollen was rapid in growth on sour cherry cultivars. Sour cherry pollen had the slowest growth on

'Meteor'. The ploidy level at the gametic stage could affect pollen tube growth rate between pollen of the diploid sweet cherry and pollen of the tetraploid sour cherry on sour cherry pistils. Moreover, partial and complete self-incompatibility on sour cherry seems to be more complex to understand based on the presence of a fertility restoring allele (or alleles) from one of the believed sour cherry parents, the tetraploid Prunus fruticosa, and considering that sour cherry is an allotetraploid.

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CHAPTER II

INBREEDING, COANCESTRY, AND FOUNDING CLONES OF ALMONDS OF CALIFORNIA, MEDITERRANEAN SHORES, AND RUSSIA

SUMMARY:

The cultivated almond, Prunus dulcis (Miller) D.A Webb, has spread progressively since antiquity from along the Mediterranean shores to the United States (U.S.), South Africa, and Australia. To satisfy market demands and improve cultivars, the recurrent use of four selections as parents in the U.S. breeding programs has resulted in a mean inbreeding coefficient (F) within the U.S. germplasm collection of 0.022. In France, a single cultivar, 'Ferralise', has an inbreeding value of $F = 0.250$, while cultivars of other almond producing countries are noninbred ($F=0$). Due to the use of common parents, the U.S., Russian, and Israeli cultivars share coancestry, while coancestries also exist between French and Spanish almond germplasm. Cultivars of known parentage in the U.S., Russia, Israel, France, and Spain trace back, respectively, to 9, 8, 3, 4, and 3 founding clones. Almond breeding programs might, in the future, narrow the genetic base of almond germplasm, thereby limiting genetic gain.

INTRODUCTION:

Genetic diversity of crop plants decreases the likelihood of crop losses to insects, diseases, and unfavorable weather conditions. Maximizing genetic diversity is also important in breeding programs, since it maximizes the potential gain from

selection. Yet, Prunus cultivars grown in the U.S. have a very narrow genetic base. Sour cherry (P. cerasus) production in the U.S. is a monoculture of one variety, and most commercial peach (P. persica) varieties trace back to six parental cultivars (Scorza et al., 1985). In almond breeding programs, the extensive use of two cultivars, 'Nonpareil' and 'Mission', suggest that the almond germplasm base may be similarly narrow.

The cultivated almond [synonymous P. amygdalus Batsch and P. communis L. (Kester et al., 1991)] is believed to have originated from the wild species Amygdalus communis (Evrinov, 1958; Grasselly and Crossa-Raynaud, 1980; Kester, 1990; Kester et al., 1991; Kester and Asay, 1975). Amygdalus communis is thought to be derived from hybridization among several wild species of the subgenus Amygdalus such as P. fenzliana, P. bucharica (Grasselly and Crossa-Raynaud, 1980; Kester and Asay, 1975), P. ulmifolia (Evrinov, 1958; Kester and Asay, 1975), and possibly P. kuramica (Grasselly and Crossa-Raynaud, 1980; Kester et al., 1991) and P. kotschii (C. Grasselly, personal communication). The native habitats of the cultivated almond are between 700 and 1700 m on the Kapet Dag Mountains between Iran and Russia and on the Tian Shan Mountains between western Mongolia and Russia (Grasselly and Crossa-Raynaud, 1980; Grasselly, 1976; Kester, 1990; Kester and Asay, 1975). Almond cultivation began during the third millennium B.C. (Socias I Company, 1990) with sweetkerneled selections that

arose by mutation within wild populations of normally bitter seedlings (Grasselly, 1976; Kester, 1990). Cultivated almonds were introduced to Greece before 350 B.C. (Kester, 1990; Socias I Company, 1990) and spread around the Mediterranean through commercial routes (Grasselly and Crossa-Raynaud, 1980; Kester, 1990; Kester et al., 1991; Kester and Asay, 1975; Socias I Company, 1990). The Arabs introduced almonds into North Africa and the Iberian peninsula during the 6th and 7th century A.D (Kester, 1990). The introduction of almonds into America, Australia and South Africa occurred between 1850 and 1900 (Kester, 1990). Currently almond culture is concentrated in three main world regions: Asia, the shores of the Mediterranean sea, and California. Limited production is found in Australia, South Africa, Argentina, and Chile (Kester et al., 1991).

Since antiquity, the cultivated almond has been propagated by seed and, therefore, has been more likely to exhibit more genetic change than a clonally propagated species would. As a result of selection pressure, the domesticated species progressively differentiated into separate geographical ecotypes in the differing environments (Grasselly, 1976; Grasselly and Crossa-Raynaud, 1980; Kester, 1990). Cultivars were selected from seedling almond populations, grafted to propagate desirable clones, and later established in commercial orchards (Kester, 1990; Kester et al., 1991; Kester and Asay, 1975, Socias I Company, 1990). Most of the leading

cultivars in the world originated from chance seedlings selected from local gene pools (Kester et al., 1991).

Almond production and cultivar development followed different patterns in different parts of the world: 1) Seedlings and a few locally selected and vegetatively propagated cultivars are grown commercially in Afghanistan, Bulgaria, India, Iraq, Iran, Morocco, Pakistan, Romania, Syria, Turkey, and Yugoslavia.

2) Active breeding and evaluation programs exist in Australia, Greece, Israel, Italy, Spain, and Tunisia, but most of the major cultivars originated from chance seedlings from local ecotypes.

3) In France, the former Soviet Union, and U.S., the almond industries rely primarily on released cultivars from breeding programs, and old seedling or clonally selected cultivars from landraces exist only in germplasm preservation collections.

Almond is an obligate outcrosser and susceptible to inbreeding depression characterized by leaf abnormalities and reduction in vigor, flower number, fruit set, seed germination, seedling survival, and disease resistance (Grasselly and Olivier, 1976; Grasselly et al., 1981; Grasselly and Olivier, 1981; Socias I Company, 1990; C. Grasselly and D. Kester, personal communication). When the 'Tuono' cultivar from the Puglia region of Italy was crossed with unrelated cultivars, no inbreeding depression was reported. However, when 'Tuono' was crossed with other

cultivars of the Puglia region or self-pollinated, inbreeding depression occurred, as expressed by low vigor and a longer juvenile period (Socias I Company, 1990). In cultivar development, when self-pollination or sib-mating are practiced, the level of inbreeding in the progeny population increases. The objective of these conservative crosses, selfs or related crosses, is generally to maintain the uniformity in kernel traits required by the industry. As a result, there is fixation at desirable loci with an associated reduction of fitness due to a loss of heterozygosity. The extensive use of the 'Nonpareil' and 'Mission' cultivars in breeding programs raises a concern of possible inbreeding depression in almond breeding programs. The objective of the present study was to compare the level of inbreeding, coancestry, and the genetic contribution of founding clones among almond germplasm in different almond producing countries.

MATERIALS AND METHODS:

Pedigrees of almond cultivars were collected from published sources (Anonymous, 1977; Barbera et al., 1984; Bastide and Souty, 1976; Brooks and Olmo, 1972; Brooks and Olmo, 1982; Chessa and Pala, 1985; Costetchi, 1967; Egea et al., 1984; Fanelli, 1939; Felipe, 1976; Felipe, 1984; Felipe and Socias I Company, 1985; Felipe and Socias I Company, 1987; Georgio et al., 1985; Grasselly and Crossa-Raynaud, 1980;

Jaouani, 1976; Kester et al., 1991; Kester et al., 1984; Kester et al., 1985; Monastra et al., 1984; Serafimov, 1976; Spiegel-Roy, 1976; Spiegel-Roy and Kochba, 1976a; Spiegel-Roy and Kochba, 1976b; Spiegel-Roy et al., 1982; Stylianides, 1976; Stylianides, 1977; Vargas Garcia, 1975; Vlasic, 1976; Wood, 1924), and breeding records. Parental relationships for many cultivars of unknown origin have been defined by isozyme techniques (Hauagge et al., 1987), or through pollen incompatibility studies (Crossa-Raynaud and Grasselly, 1985; Godini et al., 1977; Kester et al., 1985). Pedigrees for 427 almond cultivars from different almond producing countries were obtained; however, only 124 cultivars were included in the present study. The other 303 cultivars are of unknown parentage. Of these 124 cultivars, 86 were American, 12 Russian, 6 Israeli, 13 French, 5 Spanish, and 3 Italian.

The inbreeding coefficient (F), given by the following formula, is defined as the probability that 2 genes at any locus in an individual are replicates of one and the same gene in a previous generation. These genes are said to be "identical by descent" (Wright, 1922).

$$F_x = \sum \left[\left(\frac{1}{2} \right)^{n_1 + n_2 + 1} (1 + F_A) \right].$$

n_1 = number of generations from one parent back to the common ancestor.

n_2 = number of generations from the other parent back to the

common ancestor.

F_A = inbreeding coefficient of the common ancestor.

Estimation of the level of inbreeding by calculation of the inbreeding coefficient gives a reasonable approximation of the probability of fixation, even when the initial gene frequencies are not known (Wright, 1922). Considering that almond is an obligate outcrosser because it is self-incompatible, all parents of unknown origin were assumed non inbred and unrelated. The seed parent involved in an open-pollination was also assumed to be unrelated to the pollen parent. Inbreeding coefficients were calculated using a computer program of Hancock and Siefker (1982).

The coancestry coefficient (CC) of perspective progeny of 2 individuals is equal to one half the covariance of the parents. Using the same program for F calculations, the CC of 2 cultivars was calculated as F of their prospective progeny knowing that F of an individual is equal to the CC of its parents. The CC equals 0.500 for self-pollination, 0.250 for parent-offspring and full-sib matings, 0.125 for half-sib matings, and 0.063 for first cousin matings. Parentage of a mutant of a cultivar is considered to be the same as parentage of the mutated cultivar. Thus only the CC value of the original cultivar is presented. However, the CC values of all the cultivars, the mutants plus the original cultivar, were considered for mean calculations.

The genetic contribution (GC) of a founding clone to a cultivar was calculated as described by Sjulín and Dale (1987):

$$GC = \sum_{i=1}^x \left(\frac{1}{2}\right)^n$$

n = number of generations in a pedigree pathway between the founding clone and the cultivar.

x = number of pathways between the founding clone and the cultivar.

RESULTS:

Inbreeding coefficients: Only 10 almond cultivars had inbreeding coefficients different than zero (Table 1). Inbreeding coefficients of U.S. cultivars ranged from 0 to 0.375 (Appendix 1) with 9 of the 86 cultivars evaluated having $F > 0$ (Table 1). The mean inbreeding coefficient for the U.S. cultivars was 0.022. Except for the French cultivar 'Ferralaise', with $F=0.250$, all the remaining almond cultivars in France, Russia, Spain, and Israel are noninbred ($F=0$) (Appendix 1).

Founding clones: The almond cultivars in the U.S. germplasm collection trace back to 9 cultivars with 'Nonpareil',

Table 1: Country of origin, parentage, and inbreeding coefficients for 10 almond cultivars.

Country of origin	Cultivar	Presumed or reported parentage ²	Inbreeding coefficient (F)
U.S.	Sonora	21-19W [Nonpareil x (Nonpareil x (5a-20) Eureka) Al-30] x [Nonpareil x (Nonpareil x Eureka) Al-30]	0.375 22-20
U.S.	Solano	21-19W [Nonpareil x (Nonpareil x (5a-3) Eureka) Al-30] x 22-20 [Nonpareil x (Nonpareil x Eureka) Al-30]	0.375
U.S.	Emerauld	Mission x (Nonpareil x Mission)	0.250
U.S.	Profuse	Nonpareil x Jordanolo	0.250
U.S.	Wawona	Ruby x Mission	0.250
U.S.	Kapareil	Nonpareil x 24-6[Sel. A525 (Nonpareil x Eureka) x Eureka]	0.125
U.S.	Milow	Nonpareil x 24-6[Sel. A525 (Nonpareil x Eureka) x Eureka]	0.125
U.S.	Vesta	Solano (5a-3) x late blooming sport of Nonpareil	0.094
U.S.	Davey	Nonpareil x Sans Faute	0.063
France	Ferralise	Ferraduel x Ferragnes	0.250

²The rule of seed parent being at left of the cross is not respected because the direction of the cross was unknown.

'Mission', and the French 'Princesse' and 'Languedoc', representing the highest genetic contribution (GC) (Table 2). 'Nonpareil', a seedling of 'Princesse', contributes 37.9% in the genetic make-up of U.S. cultivars. This cultivar is related to 65% of the cultivars studied. 'Mission' (syn. 'Texas') has a GC of 30.2% and a coancestry relationship with 49% of the cultivars under study. 'Princesse' has a GC of 21.6% , while 'Languedoc' has a GC of 14.1%. The gene pool in California is dominated by descendants of 'Nonpareil' and 'Mission' (Hauagge et al., 1987, Kester et al., 1991). 'Nonpareil', 'Nec Plus', 'I.X.L', and 'Mission' are considered founding clones, even though their parentage is known (Appendix 1), because of their extensive use (mostly 'Mission' and 'Nonpareil') in breeding programs (Appendix 2). In addition, they originated from the first generation of selected almonds. The maternal parent of 'Nonpareil' (as well as of 'Nec Plus Ultra' and 'I.X.L') is believed to be a variety known in California as 'Princesse' or 'Prince's' which originated in the Languedoc area of France (Grasselly and Crossa-Raynaud, 1980). The California 'Languedoc' is apparently different from the French cultivar in the French collection known as 'Languedoc 320' (Kester et al., 1991).

The Russian cultivars trace back to 8 founding clones (Appendix 3, Table 2). Three of the founding clones are of Russian origin ('Nikitski 62', 'Nikitski 1', and 'Nikitski 53'), while the 5 others are from France ('Princesse' and

Table 2: The percent genetic contribution of founding clones over all the cultivars in their respective groups outlined in the pedigrees in Appendices 2-6.

Founding clone	Country of origin	Genetic contribution within each country %
U.S. Germplasm:		
Nonpareil	U.S.	37.9
Mission	U.S.	30.2
Princesse	France	21.6
Languedoc	France	14.1
I.X.L	U.S.	3.9
Eureka	U.S.	2.3
Harriott	U.S.	1.6
Nec Plus	U.S.	1.3
Swanson	U.S.	0.7
Russian germplasm:		
Nikitski 62	Russia	38.9
Princesse	France	16.7
Nikitski 1	Russia	11.1
Nonpareil	U.S.	11.1
Languedoc	France	11.1
Nikitski 53	Russia	5.6
Fragullio	Italy	5.6
Reams	Italy	5.6
French germplasm:		
Cristomorto	Italy	41.7
Ai	France	33.3
Tuono	Italy	16.7
Ardechoise	France	8.3
Spanish germplasm:		
Tuono	Italy	50.0
Ferragnes	France	16.7
Tardive	France	16.7
Israeli germplasm:		
Greek	Israel	25.0
Marcona	Spain	25.0
Princesse	France	25.0

'Languedoc'), Italy ('Fragullio' and 'Reams'), and U.S. ('Nonpareil'). The dominant cultivar used in Russian breeding programs is 'Nikitski 62' (GC = 38.9%), followed by 'Princesse' (GC = 16.7%). 'Princesse', in Russia, is different from the 'Princesse', parent of 'Nonpareil', in the U.S. and 'Poriah 10' in Israel (C. Grasselly, personal communication), even though both cultivars are originally from France. 'Nikitski 1', 'Languedoc', and 'Nonpareil' have a GC = 11.1%.

The French almond breeding program is characterized by the extensive use of two founding clones 'Ai' (France) and 'Cristomorto' (Italy). Both cultivars have a GC of 35.7%, followed by 'Tuono' (Italy) (GC = 14.3%), and 'Ardechoise' (France) (GC = 7.1%) (Table 2). The French cultivars released from breeding programs trace back to 4 cultivars, 2 of Italian origin and 2 from France (Appendix 4). All the other French almond cultivars are of a chance seedling origin with unknown parentage except some speculative parentage relationship between old cultivars such as 'Fourcouronne', 'Tournefort', and 'Tardive de la Verdière' (Grasselly and Crossa-Raynaud, 1980).

The Spanish breeding program has released 3 cultivars to date (Appendix 5). From this material there are 3 founding clones: 'Tuono' from Italy (GC = 50%), 'Ferragnes' and 'Tardive de la Verdiere' from France (GC = 16.7%) (Table 2).

In Israel, 8 cultivars are of Israeli origin. Four of them have been obtained through breeding programs (Appendix 6)

involving 3 founding clones from 3 different countries ('Greek' from Israel, 'Marcona' from Spain, and 'Princesse' presumably from France, but probably imported from U.S.). The GC of each of these cultivars is 25% (Table 2).

Coefficients of coancestries: Even though the inbreeding coefficients of the almond cultivars are low (Appendix 1), cultivars released from breeding programs show important coancestry relationships through the repeated use of a few superior parents.

U.S. germplasm: Coefficients of coancestries (CC) of cultivars in the U.S. germplasm range between 0 and 0.50 (Table 3). The average CC values for individual cultivars paired with all other cultivars range between 0 and 0.15 with an overall mean of 0.080 for the 86 cultivars. Except for 12 cultivars of unknown origin and 'Nonpareil' and 'Mission', which are unrelated, all of the remaining 72 cultivars (84%) are interrelated. Seven percent of the cultivars represent a parent-offspring relationship (CC = 0.25) while 2% are full-sibs. Fourteen percent represent a half-sib relationship (CC = 0.125) and 4% have CC = 0.063 (first cousin relationship). On the average, every cultivar is related to 38 other cultivars with a range between 1 ('Swanson' = founding clone) and 69 (all 'Nonpareil' x 'Mission' hybrids) (Appendix 2).

Russian germplasm: Russian cultivars have CC values between 0 and 0.250 (Table 4). The average CC value over all the

Table 3: Coefficients of concordance for U.S. almond cultivars.

Cultivars	1 ^a	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	mean ^b
1 Arbuckle ^c	250	125	125	016	250	125	063	156	125	- ^d	063	125	156	125	125	250	125	125	063	031	125	250	063	031	125	125	108	031	031	108	108	125	031	125	203	-	125	147
2 Battico	-	-	-	188	125	125	125	125	-	-	-	-	-	-	-	125	250	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	069
3 Davey	047	070	-	-	-	094	140	-	188	141	176	141	-	-	-	176	140	-	281	094	094	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	188
4 Denny	-	-	-	-	-	063	016	-	125	016	020	016	-	-	-	020	016	-	031	031	250	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	063
5 Denny	008	-	188	094	063	-	031	063	078	063	125	250	-	-	-	188	078	063	125	016	108	063	031	016	108	063	094	016	016	094	063	016	063	289	-	-	-	063
6 Empire	-	-	-	-	-	125	063	125	-	-	-	-	-	-	-	125	250	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	064
7 Fritz	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125	250	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	064
8 Golden Street	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	037
9 Granada	031	-	-	-	-	-	-	-	250	031	039	031	125	250	039	031	125	063	031	125	063	031	125	063	031	125	031	047	125	047	047	031	125	063	203	-	-	125
10 Harriet	250	063	250	156	125	-	-	-	250	063	250	156	125	-	-	156	125	-	250	063	031	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
11 Harriot	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	062
12 I.X.L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	063	078	063	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	060
13 Jordenolo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	156	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	064
14 Knapwell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	156	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	104
15 Knapwell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	156	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	104
16 Langquod (f)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
17 Mission	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	129
18 Milow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	156	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	104
19 Moneytree	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	063	031	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	078
20 Moneytree	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	063	031	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	078
21 Noppareil ^e	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125	063	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
22 Ne Plus Ultra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	063	031	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
23 Northland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
24 Padre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
25 Padre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
26 Pristine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
27 Sans Faute	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
28 Sydney Special	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
29 Sonora	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
30 Sonora	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
31 Spencer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
32 Utah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
33 Vesta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
34 Vesta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
35 Vesta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
36 Ureka	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
37 Princess (f)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	250	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	106

CC values are a ¹⁰⁰ coefficient of concordance measure of origin of foreign cultivars used as parents. F = France.

Cultivars with mean CC < 8 are not included in the table, but are considered in mean calculations.

Numbers across top of table refer to cultivar numbers at far left of table.

Numbers across bottom of table refer to cultivar numbers at far left of table.

Mean coefficients of concordance calculated with standard error.

Mean coefficients of concordance calculated with standard error.

Represent all "Noppareil" & "Mission" cultivars, full size of "Arbuckle".

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Represent all "Noppareil" & "Mission" cultivars, full size of "Arbuckle".

Table 4: Coefficients of coancestries for Russian almond cultivars used in breeding programs.

Cultivars	1 ^a	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Mean ^a
1 Bumagnoskorlupii	.063	.063			.125	.125	-	-	.063	.125	.063	.250	-	.063	.125	-	.250	.077
2 Desertnii		.125		-	.125	.250	.250	-	.250	-	.125	.063	-	.125	-	-	-	.081
3 Iaitinski				-	.125	.250	-	-	.125	-	.125	.063	.250	.125	-	-	-	.074
4 Krinski					-	-	-	.250	-	-	-	-	-	.125	-	.250	-	.038
5 Miagkoskorlupii						.250	-	-	.125	.250	.250	.125	-	.125	-	-	-	.096
6 Nikitski 62							-	-	.250	-	.250	.125	-	.125	-	-	-	.103
7 Nikitski 1								-	.250	-	-	-	-	.250	-	-	-	.030
8 Nikitski 53								-	-	-	-	-	-	-	-	-	-	.015
9 Nik. Podznetvetuse									-	-	.125	.063	-	.125	-	-	-	.081
10 Princesse(F)										.250	.250	-	-	-	-	-	-	.066
11 Primorski											.125	-	-	.125	-	-	-	.092
12 Preanii												.125	-	-	.063	.125	-	.250
13 Reams(F)													-	-	-	-	-	.015
14 Sovietski													-	-	-	.250	-	.081
15 Fragillio(I)													-	-	-	-	-	.015
16 Languedoc(F)													-	-	-	-	-	.030
17 Nonpareil(U.S.)													-	-	-	-	-	.059

Letters between parentheses represent country of origin of foreign cultivars used as parents;

F - France, I - Italy, U.S. - United States of America.

*Numbers across top of table refer to cultivar numbers at far left of table.

*Dashes indicate no inbreeding of the known parents.

*Mean coefficients of coancestry calculated with dashes = zero.

cultivars tested is 0.061. CC mean values for cultivars showing coancestry relationships and taken individually vary between 0.015 and 0.103. Ten percent of the cultivars from breeding programs have a parent-offspring relationship (CC = 0.250) and 4% are full-sibs (CC = 0.250). Fifteen percent of these cultivars represent a half-sib relationship (CC = 0.125), and 5% are of first cousin type coancestry (CC = 0.063). Every released cultivar from a controlled cross is related to at least seven other cultivars (Appendix 3).

French germplasm: The overall mean CC between cultivars released through French breeding programs is 0.121 (Table 5). 'Ferralise' represents the highest coancestry value (CC = 0.375) with its parents 'Ferragnes' and 'Ferraduel'. Every cultivar is related to at least 6 other cultivars, thus presenting a CC different than zero (Appendix 4). Eight percent of the cultivars have a full-sib relationship and 20% have a parent-offspring relationship (CC = 0.250). Nineteen percent are half-sibs (CC = 0.125), and 1% are first cousins (CC = 0.063).

Spanish germplasm: CC values for Spanish cultivars vary between 0 and 0.250 with an overall mean of 0.108. Three cultivars are half-sibs (CC = 0.125). The other CC's different from zero are parent-offspring relationships (CC = 0.250) (Table 6). Every released cultivar is related to at least 3 other cultivars (Appendix 5).

Table 5: Coefficients of coancestries for French almond cultivars used in breeding programs.

Cultivars	1 ²	2	3	4	5	6	7	8	9	10	11	Mean ^x
1 Belle		.125	.125	.125	— ^y	—	.063	.063	.250	—	—	.075
2 Ferralisse			.375	.375	.250	.125	.188	.188	.250	—	—	.188
3 Ferragnes				.250	.250	.125	.250	.250	.250	—	—	.188
4 Ferraduel					.250	.125	.125	.125	.250	—	—	.163
5 Cristomorto(I)						.250	.125	.125	—	—	—	.125
6 Ferrastar							.063	.063	—	.250	—	.100
7 Lauranne								.250	.125	—	.250	.144
8 Stelliette									.125	—	.250	.144
9 Ai										—	—	.125
10 Ardechoise										—	—	.025
11 Tuono(I)											—	.050

Letters between parentheses represent country of origin of foreign cultivars used as parents; I= Italy.

²Numbers across top of table refer to cultivar numbers at far left of table.

^yDashes indicate no inbreeding of the known parents.

^xMean coefficients of coancestry calculated with dashes = zero.

Table 6: Coefficient of coancestries for Spanish
almond cultivars used in breeding programs.

Cultivars	1 ²	2	3	4	5	6	Mean ^x
1 A-10-6		.125	.125	.250	- ^y	.250	.150
2 Ayles			.125	.250	-	-	.100
3 Moncayo				.250	.250	-	.150
4 Tuono(I)					-	-	.050
5 Tardive(F)						-	.050
6 Ferragnes(F)							.050

Letters between parentheses represent country of origin of foreign cultivars used as parents; F- France, I- Italy.

²Numbers across top of table refer to cultivar numbers at far left of table.

^yDashes indicate no inbreeding of the known parents.

^xMean coefficients of coancestry calculated with dashes = zero.

Israeli germplasm: Of 11 cultivars, 9 have been involved in breeding programs, including 3 from foreign countries (Appendix 6). CC values vary between 0 and 0.250 (Table 7). All CC's equalling 0.250 (31 % of the cultivars studied) represent a parent-offspring relationship, with the exception of a full-sib relationship between 'Solo' and 'Samish'. Fourteen percent of the coancestry relationships are of the half-sib type (CC = 0.125). Every released cultivar is related to 5 or 6 other cultivars. Some of the original parents are introduced cultivars. 'Princesse' is a French cultivar, probably introduced from the U.S., 'Nonpareil' is from the U.S., and 'Marcona' is from Spain.

Coancestry relationships among cultivars from different countries: Germplasm exchange between almond breeders from different countries resulted in the common use of some cultivars as parents. When mean CC's across cultivars within countries are considered, U.S., Russian, and Israeli almond cultivars share common parentage (Table 8). The mean CC between U.S. and Russian almond cultivars is 0.030, which is half the CC mean values within U.S. and Russian cultivars (0.057 and 0.061, respectively). This parental relationship is explained by the use 'Languedoc,' old French cultivar, in breeding programs of both countries, and from the use of 'Nonpareil' from the U.S. by Russian breeders. The mean CC between U.S. and Israel is 0.035. The French cultivar 'Princesse' and the U.S. cultivar 'Nonpareil' are found in

Table 7: Coefficients of coancestries for Israeli almond cultivars used in breeding programs.

Cultivars	1 ²	2	3	4	5	6	7	8	9	Mean ^x
1 Dagan		.250	.125	.125	.031	.250	— ^y	.063	.125	.108
2 Poriah 10			—	—	.063	—	—	.125	.250	.076
3 Solo				.250	.125	.250	.250	—	—	.111
4 Samish					.125	.250	.250	—	—	.111
5 Kochba						—	.250	.250	.125	.108
6 Marcona (S)							—	—	—	.083
7 Greek								—	—	.083
8 Nonpareil (U.S.)									.250	.076
9 Princesse (F)										.083

Letters between parentheses represent country of origin of foreign cultivars used as parents; F= France, S= Spain, U.S.= United States of America.

²Numbers across top of table refer to cultivar numbers at far left of table.

^yDashes indicate no inbreeding of the known parents.

^xMean coefficients of coancestry calculated with dashes = zero.

Table 8: Mean of coancestry coefficients among almond cultivars from 5 almond producing countries.

Country	1 ²	2	3	4	5
1 U.S.A	0.080	0.030	- ^y	-	0.035
2 Russia		0.061	-	-	0.013
3 France			0.121	0.067	-
4 Spain				0.108	-
5 Israel					0.093

²Numbers across top of table refer to cultivar numbers at far left of table.

^yDashes indicate no inbreeding of the known parents.

pedigrees of cultivars from both countries. 'Princesse' and 'Nonpareil' are also the 2 common cultivars used by Russian and Israeli breeders, resulting in a CC of 0.013 between the 2 countries. In addition, there is a coancestry relationship among cultivars between Spain and France. This coancestry relationship (CC = 0.067) resulted from the common use of the Italian cultivar 'Tuono' in both breeding programs and by the use of 'Ferragnes', a French release, in Spanish breeding programs.

CONCLUSION:

The repeated use of a few founding clones and their progeny as parents in almond breeding programs may result in loss of genetic variability and an increase of inbreeding depression in future generations. This is of particular concern, since new cultivars may eventually replace the local seedling ecotypes currently in cultivation. Similar situations have been reported for numerous species (Hancock and Siefker, 1982; Lyrene, 1983; Martin, 1982; Mendoza and Haynes, 1974; Reynders and Monet, 1987; Scorza et al., 1985; Sjulín and Dale, 1987).

Most cultivars presently grown are F1 hybrids of unrelated parents (e.g., Nonpareil and Mission in the U.S.). The mean inbreeding coefficient for U.S. cultivars is lower

than that of plums (Byrne, 1989), and 4.5 to 8 times lower than that of peaches (Reynders and Monet, 1987; Scorza et al., 1985). These results suggest that limited inbreeding has occurred in U.S. almond germplasm so far. However, the high degree of coancestry may limit future progress and introduce undesirable traits (e.g, noninfectious bud-failure). The outstanding kernel characteristics and industry importance of 'Nonpareil' led to it being used in breeding programs and crossed to only a few other cultivars as donor parents for specific traits such as late bloom from 'Mission' (Kester et al., 1991; D. Kester personal communication). Aside from the extensive breeding use of 'Nonpareil' and 'Mission', these two cultivars represent, respectively, 65% and 25% of commercial almond production in California (Hauagge et al., 1987). This uniformity increases the vulnerability of California almond production to yield fluctuations due to hazards such as the bud failure disorder that is frequent with 'Nonpareil' and its descendants, which represent 48% of the cultivars examined (Kester, 1969; Kester, 1970).

Almond cultivars in other countries, except the French cultivar 'Ferralise', are noninbred. They are mostly from chance seedlings, with a limited number of cultivars from controlled crosses. The highest number of cultivars showing inbreeding are from advanced breeding programs.

The major objectives in Russian breeding programs are frost and cold resistance combined with nut quality.

'Nikitski 62', known for its late bloom and cold hardiness, is a frequent parent (Denisov, 1988; Rikhter, 1964; Rikhter, 1969).

In Western Europe and North Africa, the main objectives in breeding almonds are similar, i.e. late blooming and self-compatibility (Grasselly, 1984). As a result, only a few common cultivars are being used extensively as parents, such as 'Tuono', 'Ferragnes', 'Ai', and 'Cristomorto'. Almond breeding programs in different almond producing countries are characterized by the use of a few superior genotypes as parents. Clonal selection of superior genotypes, either as new varieties or as progenitors, has provided substantial progress in important commercial traits. The diverse almond germplasm in several European countries is already being replaced by a few leading and superior cultivars (Grasselly, 1984). This situation, favored by germplasm exchange, will probably increase coancestry relationships between released almond cultivars of different European countries, and might, in the future, limit genetic gain, narrow the almond genetic base, and increase the hazard of epidemics.

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Appendix 1: Parentage and inbreeding coefficients of almond cultivars grown in the U.S., Russia, Israel, France, Spain, and Italy.

Cultivar	Presumed or reported parentage ²	Inbreeding coefficient (F)
<u>U.S. germplasm</u>		
Sonora (5a-20)	21-19W [Nonpareil x (Nonpareil x Eureka) A1-30] x 22-20 [Nonpareil x (Nonpareil x Eureka) A1-30]	0.375
Solano (5a-3)	21-19W [Nonpareil x (Nonpareil x Eureka) A1-30] x 22-20 [Nonpareil x (Nonpareil x Eureka) A1-30]	0.375
Emerauld	Mission x (Nonpareil x Mission)	0.250
Profuse	Nonpareil x Jordanolo	0.250
Wawona	Ruby x Mission	0.250
Kapareil	Nonpareil x 24-6[Sel. A525 (Nonpareil x Eureka) x Eureka]	0.125
Milow	Nonpareil x 24-6[Sel. A525 (Nonpareil x Eureka) x Eureka]	0.125
Vesta	Solano (5a-3) x late blooming sport of Nonpareil	0.094
Davey	Nonpareil x Sans faute	0.063
Arbuckle*	Non pareil x Mission	0
Bigelow	unknown	0
Bonita*	Nonpareil x Mission	0
Ballico	Mission open pollination (o.p.)	0
Bell ^y	Nec Plus mutation	0
Burbank	unknown	0
Butte	Nonpareil x Mission	0
Carmel*	Nonpareil x Mission	0
Craven	unknown	0
Carrión*	Nonpareil x Mission	0
Cressey	mutation of Nonpareil	0
Drake	unknown	0
Dehn	Northland o.p.	0
Empire	Mission x peach-almond hybrid	0
Elsie*	Nonpareil x Mission	0
Eureka	unknown	0
Fritz*	Mission o.p.	0
Golden street	Languedoc o.p.	0
Godde*	Nonpareil x Mission	0
Granada*	Mission x IXL	0
Grace*	Nonpareil x Mission	0

*Parentage assumed from indirect evidence, primarily isozyme studies (Hauagge et al, 1987).

^yParentage from the patent description and unconfirmed.

²The rule of seed parent being at left of the cross is not respected because the direction of the cross was unknown.

Appendix 1 (continued): Parentage and inbreeding coefficients of almond cultivars grown in the U.S., Russia Israel, France, Spain, and Italy.

Cultivar	Presumed or reported parentage ²	Inbreeding coefficient (F)
Heart*	Nonpareil x Mission	0
Hoover*	Nonpareil x Mission	0
Hallshardy	peach-almond hybrid	0
Harpareil	Nonpareil x Harriott	0
Harriott	unknown	0
Harvey*	Nonpareil x Mission	0
IXL	Princesse o.p.	0
Janice*	Nonpareil x Mission	0
Jeffries	mutation of Nonpareil	0
Jordanolo	Nonpareil x Harriott	0
Jubilee*	Nonpareil x Mission	0
Kern Royal	mutation of Nonpareil	0
Kutsch	Nonpareil o.p.	0
Livingston*	Nonpareil x Mission	0
Lamarie	unknown	0
Laprima	Princesse o.p.	0
Leweling	unknown	0
Legrand	peach-almond hybrid	0
Merced*	Nonpareil x Mission	0
Mission (Texas)	Languedoc o.p.	0
Monterey*	Nonpareil x Mission	0
Moneytree	Nonpareil o.p.	0
Monarch*	Mission o.p.	0
Norman*	Nonpareil x Mission	0
Nonpareil	Princesse o.p.	0
Nec Plus Ultra	Princesse o.p.	0
Northland	I.X.L o.p.	0
Pioneer	peach-almond hybrid	0
Planada	Tardy Nonpareil x Mission	0
Padre	Mission x Swanson	0
Peerless	unknown	0
Paxman*	Nonpareil x Mission	0
Price Cluster*	Nonpareil x Mission	0
Reinero	Nonpareil o.p.	0
Ripon	Tardy Nonpareil x Mission	0
Roy	unknown	0
Ruby	Tardy Nonpareil x Mission	0
Robson*	Nonpareil x Mission	0

¹Parentage assumed from indirect evidence, primarily isozyme studies (Hauagge et al, 1987).

²The rule of seed parent being at left of the cross is not respected because the direction of the cross was unknown.

Appendix 1 (continued): Parentage and inbreeding coefficients of almond cultivars grown in the U.S., Russia Israel, France, Spain, and Italy.

Cultivar	Presumed or reported parentage ²	Inbreeding coefficient (F)
Sans Faute	I.X.L o.p.	0
Sydney Special	I.X.L o.p.	0
Smith X.L	unknown	0
Standard	unknown	0
Spencer	Nonpareil o.p.	0
Sauret#1*	Nonpareil x Mission	0
Sauret#2*	Nonpareil x Mission	0
Swanson	unknown	0
Tardy Nonpareil	Nonpareil mutation	0
Thompson*	Nonpareil x Mission	0
Tioga	Tardy Nonpareil x Mission	0
Tokyo	Nonpareil x Mission	0
Titan	Tardy Nonpareil x Mission	0
Utah	I.X.L o.p.	0
Valenta*	Nonpareil x Mission	0
Walton	unknown	0
Yosemite	Nonpareil x Mission	0

Russian Germplasm

Bumagnoskorlupii	(Nikitski 62 x Fragillio) x Nonpareil	0
Desertnyi	Nikitski 62 x Nikitski 1	0
Krimski	Nikitski 53 x Languedoc	0
Miagkoskorlupii	Nikitski 62 x Princesse	0
Nikitski 62	unknown	0
Nikitski 1	unknown	0
Nikitski 53	unknown	0
N.Pozdnetvetusei	Nikitski 62 x Nikitski 1	0
Primorski	Nikitski 62 x Princesse	0
Preanii	(Nikitski 62 x Fragillio) x Nonpareil	0
Sovietski	Nikitski 62 x Languedoc	0
Yaltinski	Nikitski 62 x Reams	0

¹Parentage assumed from indirect evidence, primarily isozyme studies (Hauagge et al. 1987).

²The rule of seed parent being at left of the cross is not respected because the direction of the cross was unknown.

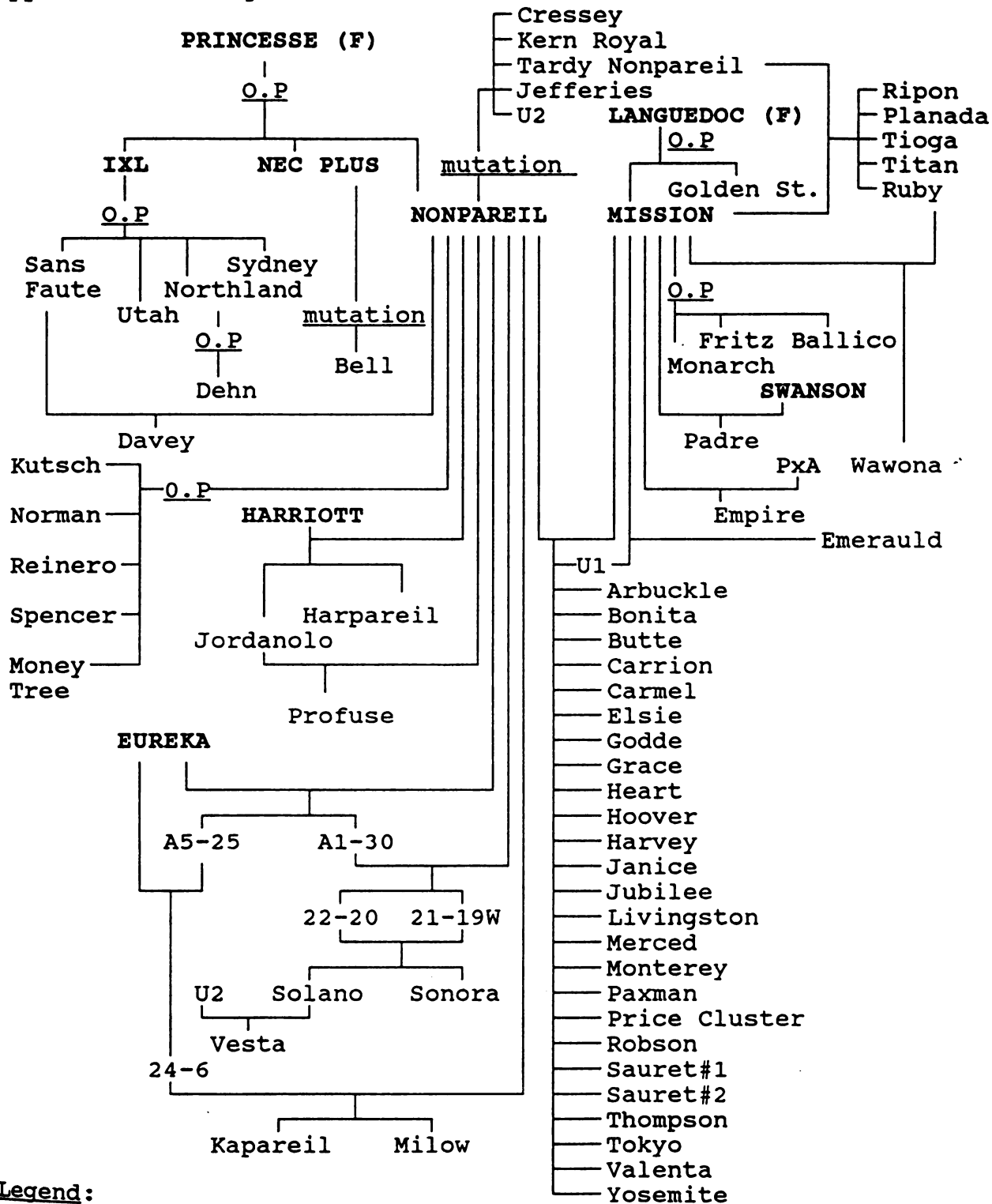
Appendix 1 (continued): Parentage and inbreeding coefficients of almond cultivars grown in the U.S., Russia Israel, France, Spain, and Italy.

Cultivar	Presumed or reported parentage ¹	Inbreeding coefficient (F)
<u>Israeli Germplasm</u>		
Dagan	Marcona x Poria 10	0
Greek	unknown	0
Poriah 10	Princesse o.p.	0
Solo	Marcona x Greek	0
Samish	Marcona x Greek	0
Kochba	Nonpareil x Greek	0
<u>French germplasm</u>		
Ai	unknown	0
Ardechoise	unknown	0
Belle d'Aurons	Ai o.p.	0
Ferralise	Ferraduel x Ferragnes	0.250
Ferragnes	Ai x Cristomorto	0
Ferraduel	Ai x Cristomorto	0
Ferrastar	Ardechoise x Cristomorto	0
Languedoc	unknown	0
Lauranne	Ferragnes x Tuono	0
Princesse	unknown	0
Steliette	Ferragnes x Tuono	0
Tardive de la Verdier	unknown	0
<u>Spanish germplasm</u>		
A-10-6	Ferragnes x Tuono	0
Ayles	Tuono o.p.	0
Jordan	unknown	0
Moncayo	Tuono x Tardive de la Verdier	0
Marcona	unknown	0
<u>Italian germplasm</u>		
Cristomorto	unknown	0
Reams	unknown	0
Tuono	unknown	0

¹Parentage assumed from indirect evidence, primarily isozyme studies (Hauagge et al, 1987).

²The rule of seed parent being at left of the cross is not respected because the direction of the cross was unknown.

Appendix 2: Pedigree of U.S. almond cultivars.

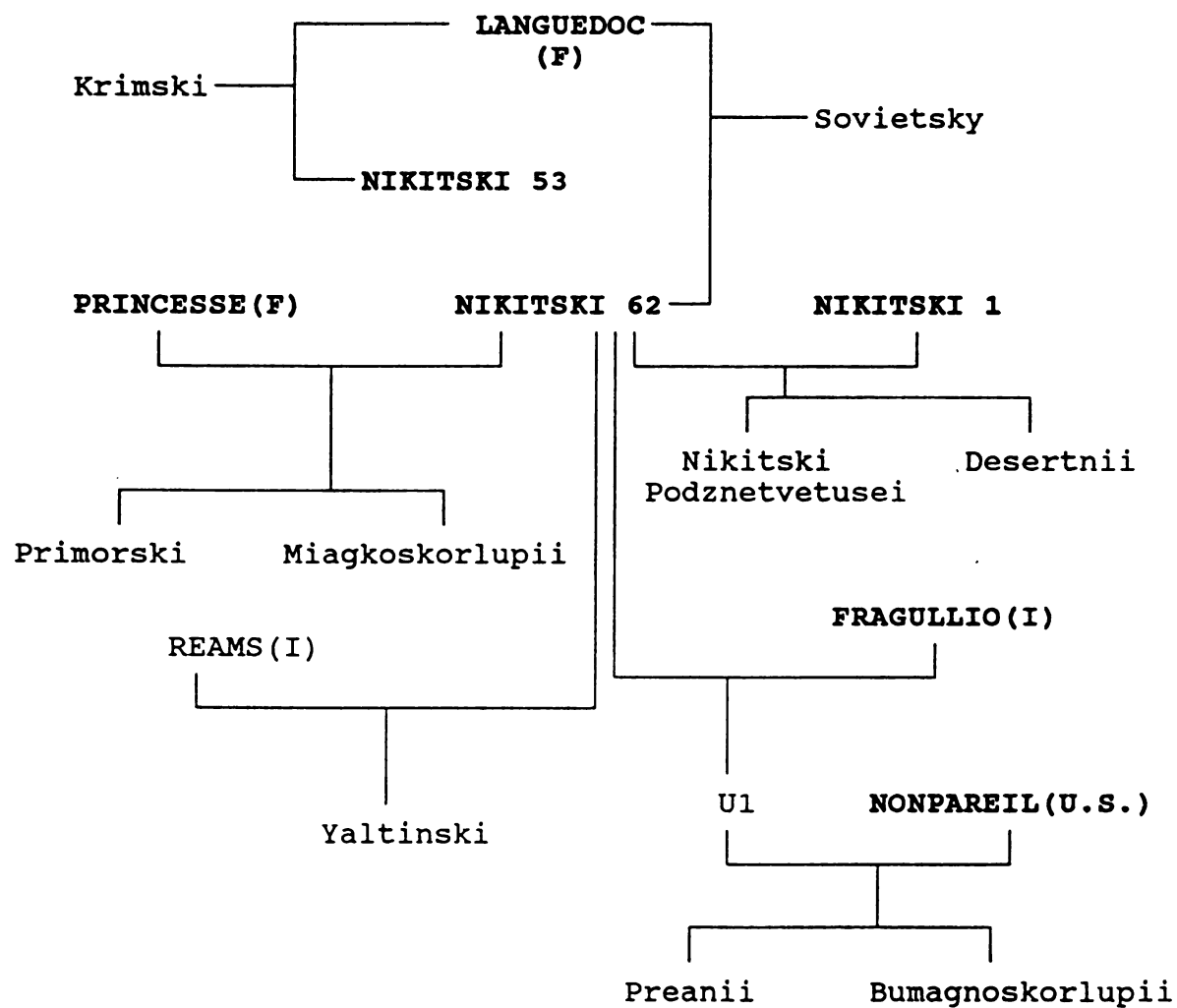


Legend :

PxA: Peach-almond hybrid. O.P.: open pollination.

U: unnamed selection. bold: founding clones. (F): French origin.

Appendix 3: Pedigree of Russian almond cultivars.



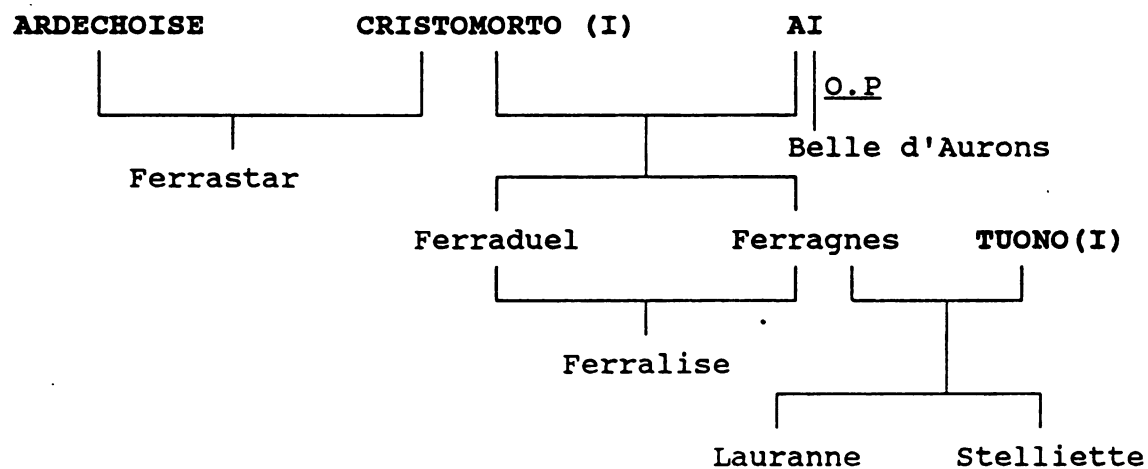
Legend:

bold: founding clones.

(F): French origin. (I): Italian origin.

(U.S.): American origin.

Appendix 4: Pedigrees of French almond cultivars.



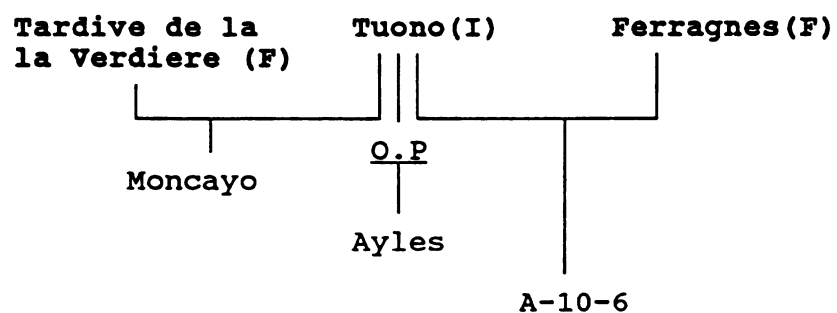
Legend:

bold: founding clones.

(I): Italian origin.

O.P.: open pollination.

Appendix 5: Pedigrees of Spanish almond cultivars.



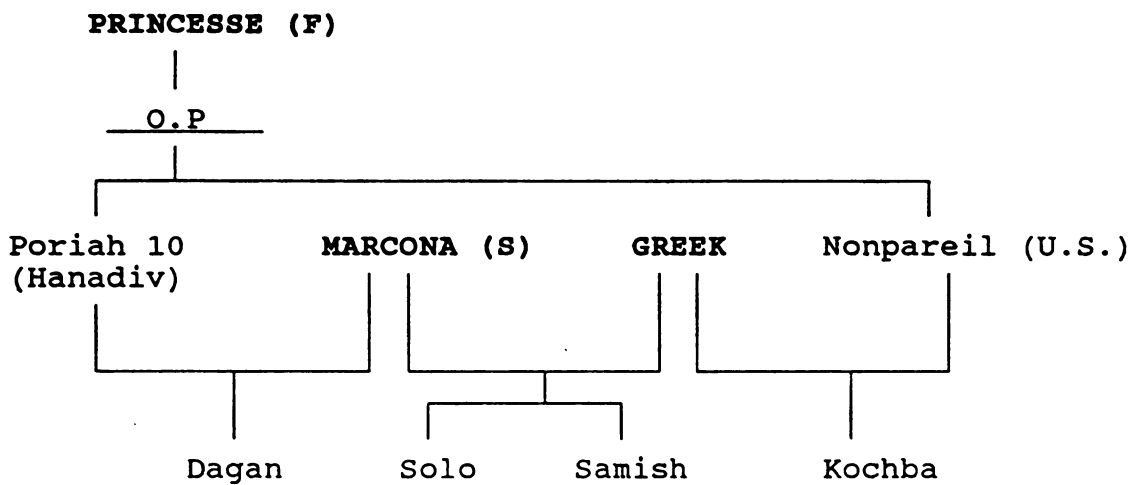
Legend:

bold: founding clones.

(F): French origin, (I): Italian origin.

O.P. : open pollination.

Appendix 6: Pedigrees of Israeli almond cultivars.



Legend:

bold: founding clones.

(S): Spanish origin, (U.S.): American origin.

O.P. : open pollination.

CHAPTER III

MORPHOLOGICAL VARIATION WITHIN COLLECTIONS OF MOROCCAN ALMOND CLONES AND MEDITERRANEAN AND AMERICAN CULTIVARS

SUMMARY:

Cultivated almond Prunus dulcis (Miller) D.A. Webb, the second most important fruit crop in Morocco after olives, is still propagated through seedlings by farmers to overcome transplanting failure of grafted trees. Collections of seedlings in southern Morocco conducted since 1975 have resulted in the selection of 87 clones from this germplasm planted at 3 experimental stations. Principal component analysis (PCA) was used to quantify morphological variation among a total of 81 selected Moroccan clones and introduced cultivars. Moroccan selections tended to be characterized by small leaves in comparison to foreign cultivars. Variability for nut and kernel traits was identified. Several clones, such as 'Ighri/13', 'Kelaa/7R', and 'B2/25R' have very good nut and kernel characteristics. However, the fruiting potential of Moroccan selections remains limited, even though some of them have a large number of spurs. No evidence was found of separate ecotypes existing in the southern Moroccan almond populations.

INTRODUCTION:

Cultivated almond was introduced to Morocco by the Carthaginians between the 5th and 4th century B.C (El Khatib-Boujibar, 1983) and by the Arabs during the 6th and 7th century (Kester et al., 1991). Almonds, the second most important fruit tree crop in Morocco after olives, occupy

107,000 hectares, and comprise 73% of all Rosaceous species in Morocco (Anonymous, 1990). Production is approximately 40,000 metric ton/year, and exportations of bitter almonds vary between 1100 and 1300 metric ton/year (Anonymous, 1990). Almonds are grown in Morocco in several regions under different environmental conditions. They are found between 500 and 2000 m elevation, where rainfall ranges from less than 100 to 800 mm, and on a wide diversity of soils varying from deep clay to shallow, calcareous soils. About 55% of the almond trees grown in Morocco are seedlings, located primarily in the south, where this method of propagation still prevails. Five percent of the total acreage is represented by modern orchards with known cultivars, mainly 'Marcona' from Spain and two pollinizers 'Fournat de Brezenaud' from France and 'Ne Plus Ultra' from the United States (Laghezali, 1985). Recently, 2 French cultivars, 'Ferragnes' and 'Ferraduel', have become popular. The modern sector accounts for 80% of the total almond production. About 40% of the almonds in Morocco have been planted in the Rif Mountains in the north, mainly by the Forestry Department to prevent soil erosion. 'Marcona' and 'Fournat de Brezenaud' have been the principal cultivars used for this purpose (Laghezali, 1985). In many cases, these cultivars have been overgrown by the rootstock, mainly 'Marcona' seedlings, due to unsuccessful grafting. Additionally, dead trees have been replanted with other unknown cultivars or seedlings, making recognition of the 2

original cultivars difficult. This almond population represents 5 million almond trees planted on 50,000 hectares.

The genetic variability in the Moroccan almond germplasm is suspected to be extensive because of the broad geographic distribution, different environmental conditions, prevalence of seed propagation and the presence of peach-almond natural hybrids (Barbeau and El Bouami, 1980b). For example, within the same seedling orchard, up to a one month difference in bloom time has been reported (Barbeau and El Bouami, 1979). In some areas, such as Tinejdad and Goulmima in the south-east, almond populations with a high proportion (up to 100%) of "doubles" (nuts containing 2 kernels), are found because double kernels have been selected by local growers. These doubles seem to present no kernel deformities for some genotypes (Barbeau and El Bouami, 1980a). Field collections of almonds for late-bloom, frost resistance, and disease and insect resistance have been carried out since 1975 in the south (Barbeau and El Bouami, 1979) as well as in the north (Laghezali, 1985). A total of 87 almond clones including 11 peach-almond hybrids were selected in the south along an east-west axis and are growing at three different experimental stations of the Institut National de la Recherche Agronomique (INRA).

The objective of the present study was to compare introduced almond cultivars and selected Moroccan clones for growth habit and leaf, nut and kernel characteristics using

Principal component analysis. Clustering of clones from similar collection areas would suggest the existence of different almond populations.

MATERIALS AND METHODS:

Plant material: Almond collections in the valleys of southern Morocco since 1975 have resulted in the selection of 87 clones, collected from Errachidia (east) to Agadir (west) (Fig. 1), which are planted at three INRA experimental stations in the following sites: Marrakech, Errachidia, and Meknes. Almonds at the experimental Station #1, located at Meknes, were not irrigated. The station is under continental climatic conditions where average annual rainfall is about 500 mm. At Station #2 at Errachidia and Station #3 at Marrakech, almonds were irrigated; annual rainfall is less than 200 mm, and conditions are arid.

Sixty-six clones, including one natural peach-almond hybrid, out the 87 Moroccan selections, plus 14 introduced cultivars and one hybrid from a 'Cristomorto' x 'Ardechoise' cross were included in the study (Table 1). They were as follows: 1) Meknes (Station #1), Nine Moroccan selections and 10 introduced cultivars; 2) Errachidia (Station #2), 37 Moroccan selections including one natural peach-almond hybrid and one almond hybrid from a cross between 'Cristomorto' and 'Ardechoise', and nine introduced cultivars; 3) Marrakech

This map of Morocco illustrates its diverse geography and administrative divisions. The northern coast is bordered by the Mediterranean Sea, with cities like Tanger and Oujda. The western coast faces the Atlantic Ocean, featuring the Strait of Gibraltar and the city of Agadir. The interior is dominated by the Atlas Mountains, with the Moyen Atlas and Anti Atlas regions clearly delineated. Major rivers such as the Oued Tensift, Oued Souss, and Oued Draa are shown flowing across the country. The map also indicates the location of the Sahara Desert to the south and the Canary Islands to the west. A scale bar at the bottom right indicates distances up to 400 km, and a north arrow is positioned in the upper right corner.

Table 1: Origin and location of cultivars and clones.

Cultivar or clone	code	origin ²	location station No ^y
<u>Foreign cultivars</u>			
Marcona	S1	Spain	1 & 2
Desmayo	S2	Spain	2
Cavaliera	I1	Italy	2
Cristomorto	I2	Italy	1 & 2
Tuono	I3	Italy	1, 2 & 3
Ai	F1	France	1
Ardechoise	F2	France	1
Ferragnes	F3	France	2 & 3
Fournat de Brezenaud	F4	France	1 & 2
Burbank	U1	U.S.A	1 & 2
Mission (Texas)	U2	U.S.A	1
Thompson	U3	U.S.A	2
Abiod	T1	Tunisia	1
Hech Ben Smail	T2	Tunisia	1
<u>Moroccan selections</u>			
Cristo.x Ardech.hybrid	M1	Morocco	2
Peach-almond hybrid.66	M2	Errachidia	2
Ksar Souk	1A	Errachidia	1
Bualuzen	8A	Meknes	1
Messaoud	8B	Meknes	1
B1/S2	1B	Errachidia	1
B1/S15	1C	Errachidia	1
B1/S17	1D	Errachidia	1
B2/S7	1E	Errachidia	1
B2/S9	1F	Errachidia	1
B2/S11	1G	Errachidia	1
B1/2L	1H	Errachidia	2
B1/6BL	1I	Errachidia	2
B1/4R	1J	Errachidia	2 & 3
B1/5R	1K	Errachidia	2
B1/7R	1L	Errachidia	2 & 3
B1/8R	1M	Errachidia	2
B1/22R	1N	Errachidia	2
B2/8R	1P	Errachidia	2
B2/11R	1Q	Errachidia	2
B2/14R	1R	Errachidia	2
B2/19R	1S	Errachidia	2
B2/22R	1T	Errachidia	2
B2/25R	1U	Errachidia	2
B1/13R	1V	Errachidia	3

²Country of origin for foreign cultivars and survey area for Moroccan clones.

^y1: Meknes, 2: Errachidia, 3: Marrakech.

Table 1 (cont.): Origin and location of cultivars and clones.

Cultivar or clone	code	origin ²	location station No
B1/15R	1W	Errachidia	3
B1/16R	1X	Errachidia	3
B1/17R	1Y	Errachidia	3
B1/2R	1Z	Errachidia	3
B1/1L	1a	Errachidia	3
B1/4L	1b	Errachidia	3
B2/2R	1d	Errachidia	3
B2/19BL	1e	Errachidia	3
B2/7R	1f	Errachidia	3
Hart/16	2A	Gheris (Erfoud) ^y	2
Hart/17	2B	Gheris (Erfoud)	2
Hart/18J	2C	Gheris (Erfoud)	3
Khorbat/3J	3A	Ferkla (Tinejdad)	2 & 3
Khorbat/6J	3B	Ferkla (Tinejdad)	3
Tizougaghine/5R	3C	Ferkla (Tinejdad)	2
Kelaa/5R	4A	Kelaa	2
Kelaa/7R	4B	Kelaa	2 & 3
Skoura/2	5A	Skoura	2
Amekchoud/1J	5B	Skoura (Amekchoud)	2 & 3
Amekchoud/3J	5C	Skoura (Amekchoud)	2 & 3
Tiflit/2R	5D	Skoura (Tiflit)	2 & 3
Tiflit/2V	5E	Skoura (Tiflit)	3
Toundout/1R	5F	Skoura (Toundout)	2 & 3
Toundout/3J	5G	Skoura (Toundout)	2 & 3
Toundout/8J	5H	Skoura (Toundout)	2 & 3
Tiliwine/8V	5K	Skoura (Tiliwine)	2 & 3
Tiliwine/8TER	5L	Skoura (Tiliwine)	3
Ighri/1R	6A	Taliwine	2
Ighri/13	6B	Taliwine	2
Ighil Noughou	6C	Taliwine	2
Ighri/12B	6D	Taliwine	3
Ighri/13B	6E	Taliwine	3
Ait Saoun/2V	7A	Draa (Ait Saoun)	2 & 3
Ait Saoun/4V	7B	Draa (Ait Saoun)	3
Ait Saoun/5V	7C	Draa (Ait Saoun)	3
Ait Saoun/6V	7D	Draa (Ait Saoun)	3
Ait Saoun/S3	7E	Draa (Ait Saoun)	3
Agdz/1BL	7F	Draa (Agdz)	2 & 3
Ircheg/2R	7G	Draa (Agdz)	2 & 3
Tamkasselt/3R	7H	Draa1 (Tamkesselt)	2 & 3
Tinzouline/3V	7I	Draa2 (Tinzouline)	2 & 3
Tinzouline/5R	7J	Draa2 (Tinzouline)	3

²Country of origin for foreign cultivars and survey area for Moroccan clones.^yRegion (town).

(Station #3), 37 Moroccan selections and two introduced cultivars.

Characters measured: Twenty-six nut, kernel, and leaf characters were measured in 1990 on 81 clones and cultivars at the three stations. Nut and kernel width and thickness were measured at the midpoint of the length, perpendicular to each other, with the width being the larger dimension. Kernel weight/nut weight is commonly used to describe shell hardness (Kester and Asay, 1975). Seven additional growth habit characters were included at Marrakech (Table 2). Five leaf and fruit samples were collected from each selection and cultivar for evaluation. Leaves were obtained from the middle portion of 1-year-old shoots 25 to 30 cm long, at approximately 1.8 meters height around the tree. Four 1-year and four 2-year-old shoots were chosen at random for growth measurements following an east-north-west-south rotation at approximately 1.8 meters height around the tree.

Data analysis: The characters for the 81 Moroccan selections and foreign cultivars were analyzed by principal component analysis (PCA). In PCA, intercorrelations among variables (components) are removed (Broschat, 1979), thus reducing the number of variables by linear combination of correlated characters into principal orthogonal axes (PC1, PC2, ..., PCn) which are not correlated (Philippeau, 1986). The first PC represents the largest variance, followed in decreasing order of variance values by succeeding axes PC2, PC3, ..., PCn.

Table 2: Morphological characters and ratios employed in the analyses.

Characters	abbreviations
<u>Leaf characters:</u>	
Leaf blade length (mm)	BL
Leaf blade width (mm)	BW
Petiole length (mm)	PetL
Vein angle (mid-vein) (d°)	Vangl
Gland number	Gnbre
Serration number(over 1cm mid-limb)	Snbre
Leaf width/leaf length	LR
Total leaf length (mm)(leaf length + petiole length)	LL
Leaf area (mm ²) (leaf length x leaf width)	LA
<u>Nut and kernel characters:</u>	
Nut weight (g)(in-shell)	NWT
Nut length (mm)	NL
Nut width (mm)	NW
Nut thickness (mm) (diameter)	NTH
Kernel weight (g)	KWT
Kernel length (mm)	KL
Kernel width (mm)	KW
Kernel thickness (mm)	KTH
Kernel weight/nut weight (shell hardness)	SH
Nut width/nut length	NR1
Nut thickness/nut length	NR2
Nut thickness/nut width	NR3
Kernel width /kernel length	KR1
Kernel thickness/kernel length	KR2
Kernel thickness/kernel width	KR3
Nut size (mm ³)(nut length x nut width x nut thick.)	Nvol
Kernel size (kern.length x kern.width x kern.thick)	Kvol
<u>Growth habit characters:</u>	
One-year-old shoot length (cm)	S1L
Number of laterals/1-year-old shoot	LAT
Number of nodes/1-year-old shoot	Nnodes1
Number of nodes/length unit (cm) of 1-year-old shoot	Node
Two-year-old shoot length (cm)	S2L
Total number of spurs/2-year-old shoot	Totsprs
Number of spurs/length unit (cm) of 2-year-old shoot	Sprs

Therefore, the first two or three PC's usually account for a large portion of the variance. This portion of the variance becomes less important when there is a large number of relatively independent variables (Daudin, 1982). PCA is used to establish correlations between variables (characters in this study) and to visualize the relationships of individuals (selections and introduced cultivars in this study) in two or three dimensional graphs.

PCA analyses were performed using the PRINCOMP procedure of the SAS statistical package (SAS Institute Inc., 1985). Data from each station were analyzed separately.

RESULTS:

At Station #1, nine Moroccan clones and 10 cultivars of foreign origin were evaluated for 26 six leaf and nut and kernel characters (Table 1). The first 3 principal components accounted for 32.4%, 23.4%, and 13.7% of the total variance respectively. Eight nut and kernel variables were highly loaded on PC1 (Table 3). From high to low absolute values, they were: nut size, kernel width, kernel weight, nut width, kernel size, kernel length, kernel thickness/kernel width, and nut length. All these traits had positive values except kernel thickness/kernel width. PC2 included 5 nut and kernel traits, 4 of which were ratios, and a single leaf trait (Table 3). They were: nut thickness/nut length, kernel width/kernel length, nut width/nut length, petiole length, kernel

Table 3: Eigenvectors of the 3 principal component axes from PCA analysis of stations 1, 2, and 3 genotypes represented in figures 2, 3, and 4.

Traits	PC Axes:	PC1			PC2			PC3		
	Stations:	St.1	St.2	St.3	St.1	St.2	St.3	St.1	St.2	St.3
Nut										
Weight		0.15	0.32 ^x	0.30	0.04	-0.06	-0.02	0.37	0.11	0.06
Length		0.25	0.31	0.19	-0.21	-0.02	-0.29	-0.04	-0.24	-0.02
Width		0.30	0.36	0.31	0.09	0.01	0.02	0.21	0.19	0.11
Thickness		0.12	0.28	0.30	0.26	-0.11	0.07	0.33	0.17	0.09
Size		0.30	0.36	0.32	0.03	-0.04	-0.06	0.20	0.04	0.06
Width/length		-0.04	0.00	0.14	0.31	0.04	0.29	0.17	0.46	0.14
Thickness/length		-0.13	-0.08	0.10	0.34	-0.05	0.32	0.16	0.41	0.10
Thickness/width		-0.23	-0.15	-0.06	0.20	-0.15	0.11	0.11	-0.11	-0.05
Kernel										
Weight		0.30	0.27	0.28	0.03	0.02	-0.11	0.13	-0.17	0.10
Length		0.28	0.27	0.17	-0.19	-0.03	-0.30	0.08	-0.32	0.04
Width		0.30	0.32	0.29	0.10	0.06	0.02	0.13	0.10	0.18
Thickness		-0.10	0.15	0.19	0.26	-0.03	0.08	0.11	0.10	0.11
Size		0.28	0.33	0.28	0.06	-0.00	-0.07	0.17	-0.05	0.15
Width/length		0.01	-0.04	0.13	0.33	0.14	0.27	0.05	0.28	0.14
Thickness/length		-0.22	-0.09	0.01	0.28	0.10	0.32	-0.01	0.20	0.04
Thickness/width		-0.26	-0.13	-0.12	0.11	-0.06	0.07	-0.03	-0.03	-0.09
Shell hardness		0.05	-0.11	-0.11	0.03	0.11	-0.09	-0.30	-0.30	-0.03
Leaf										
Blade length		0.19	-0.00	0.09	0.21	0.45	-0.20	-0.31	-0.00	0.07
Blade width		0.18	-0.01	0.01	0.08	0.35	-0.22	-0.25	-0.14	-0.15
Petiole length		0.12	0.09	0.00	0.30	0.33	-0.19	-0.14	0.05	0.11
Vein angle		-0.01	0.04	0.00	-0.11	-0.02	0.14	0.06	-0.18	0.04
Gland number		0.16	0.12	0.02	0.22	0.23	-0.01	-0.24	0.12	0.23
Serration number		-0.09	0.08	0.06	0.06	-0.06	-0.03	0.15	0.14	0.03
Width/length		0.00	-0.03	-0.06	-0.16	-0.07	-0.06	0.10	-0.17	-0.17
Total length		0.18	0.02	0.07	0.25	0.47	-0.23	-0.28	0.01	0.10
Area		0.21	-0.01	0.05	0.14	0.43	-0.25	-0.29	-0.08	-0.05
Growth habit										
a. 1 year old shoot										
Length		-	-	0.16	-	-	0.12	-	-	-0.30
Laterals number		-	-	0.19	-	-	0.08	-	-	-0.32
Nodes/shoot		-	-	0.15	-	-	0.11	-	-	-0.22
Nodes/cm		-	-	0.20	-	-	0.11	-	-	-0.31
b. 2 year old shoot										
Length		-	-	0.07	-	-	0.13	-	-	-0.28
Spurs/shoot		-	-	-0.06	-	-	0.19	-	-	0.29
Spurs/cm		-	-	-0.10	-	-	0.15	-	-	0.31

^xBold numbers are variables highly loading on separate PC axes.

PC1, PC2, and PC3 for station 1 account for 32.4%, 23.4%, and 13.7% of variance between means, respectively.

PC1, PC2, and PC3 for station 2 account for 26.8%, 16.3%, and 15.1% of variance between means, respectively.

PC1, PC2, and PC3 for station 3 account for 24.5%, 18.6%, and 11.8% of variance between means, respectively.

thickness/kernel length, and kernel thickness. The separation along PC3 was due to variation in 4 leaf characters and shell hardness that loaded negatively, plus 2 nut variables loading positively (Table 3). These variables, from high to low absolute values, were: nut weight, nut thickness, leaf length, shell hardness, leaf area, total leaf length, and leaf width.

When the cultivar and selection means were plotted on the 3 principal axes (Fig. 2), the 2 French cultivars 'Fournat' (F4) and 'Ardechoise' (F2) had coordinates on the positive extreme of PC1. These 2 cultivars had among the highest nut and kernel characteristics. On PC3, their position was explained by their longest leaves, large leaf areas, and soft shells (Table 4, Appendix 3).

'Marcona' (S1), a Spanish cultivar extensively planted in modern Moroccan orchards, had a highly positive components for all 3 axes (Fig. 2). It was distinguishable by its nut and kernel characteristics, particularly nut and kernel width that were important on PC1 (Table 4). On PC2, 'Marcona' (S1) was at the positive end due to its high nut and kernel ratios, indicating its characteristic square nut and kernel shape, and to its longest petioles (Table 4). 'Marcona' also had the thickest nut, the highest nut weight, and the hardest shells which contributed to its maximum position on PC3 (Table 4, Appendix 3).

Four Moroccan selections, 'Ksar Souk' (1A), 'B1/S2' (1B), 'B1/S17' (1D), 'B2/S9' (1F), clustered with 6 foreign

Fig. 2: Position of PC scores of introduced cultivars and Moroccan selections. Station #1.

Alphanumeric labels inside signs are abbreviations of trees and the first digit refers to the country or area of origin (table 1). Circles = clones. Diamonds = cultivars.

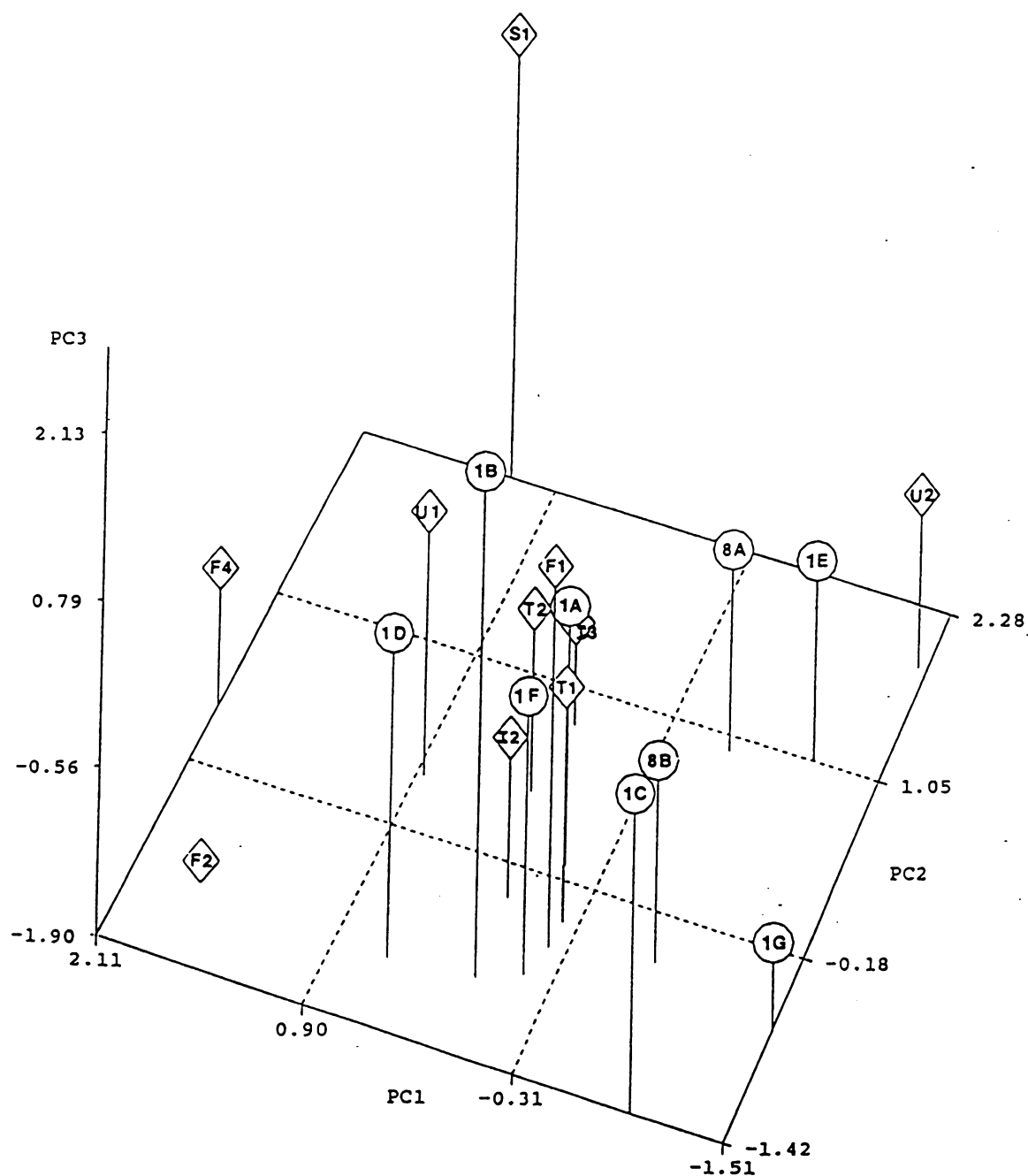


Table 4: Means of representative characters highly loading on PC1, PC2, and PC3 axes for Figure 2 (Station # 1).

Clone	NWT ²	KWT	SH	NL	NW	KL	KW	PETL	BL	BW	NR1	NR2	KR1	KR2
Marcona	7.7	1.6	0.21	33.6	30.3	23.5	17.5	29.4	96.8	23.0	0.90	0.66	0.75	0.38
Cristo.	3.4	1.1	0.35	34.8	23.4	23.3	14.6	18.0	84.0	31.4	0.67	0.46	0.63	0.29
Tuono	2.6	1.1	0.42	32.4	24.8	22.9	14.6	24.8	94.6	27.0	0.77	0.51	0.64	0.33
AI	3.2	1.4	0.45	32.3	25.1	26.0	15.6	12.4	63.8	18.6	0.78	0.50	0.60	0.51
Ardech.	3.2	1.7	0.53	51.6	24.9	29.7	15.8	23.6	108.6	26.0	0.48	0.28	0.53	0.25
Fournat	4.9	2.0	0.40	40.4	27.3	30.5	16.6	23.6	109.2	35.6	0.66	0.43	0.55	0.48
Burbank	3.4	1.7	0.51	41.6	26.0	28.7	15.1	24.4	85.0	20.4	0.63	0.44	0.53	0.59
Mission	2.7	1.2	0.46	25.7	19.9	19.6	12.9	23.2	90.2	23.6	0.78	0.64	0.66	0.84
Abiod	3.2	1.2	0.38	31.6	23.7	23.5	14.9	09.6	79.6	22.4	0.75	0.49	0.64	0.48
Hech.	2.7	1.4	0.52	32.5	24.6	24.5	15.5	23.2	85.6	24.8	0.76	0.52	0.63	0.49
KsarSouk	5.0	1.3	0.25	33.7	24.5	23.9	13.8	23.4	79.4	22.4	0.73	0.47	0.58	0.34
Bualuzen	2.8	1.2	0.43	30.0	22.6	21.8	13.4	23.6	84.2	26.4	0.75	0.58	0.62	0.42
Messaoud	4.8	1.1	0.23	37.9	21.3	24.3	11.7	10.2	69.8	20.4	0.56	0.40	0.48	0.33
B2/S7	2.6	1.1	0.41	29.1	21.4	20.9	12.6	21.6	82.8	22.2	0.73	0.61	0.60	0.43
B1/S2	6.3	1.5	0.24	38.5	24.7	28.2	14.7	14.8	59.0	20.8	0.64	0.48	0.52	0.28
B1/S17	3.9	1.6	0.43	42.7	25.5	28.2	15.1	14.2	71.2	23.0	0.60	0.40	0.54	0.30
B2/S9	3.4	1.4	0.41	37.9	22.9	26.6	14.0	17.4	71.2	22.8	0.61	0.43	0.53	0.32
B2/S11	1.8	0.8	0.43	30.0	19.1	21.0	11.2	17.0	73.6	20.6	0.64	0.45	0.54	0.36
B1/S15	3.8	1.0	0.26	34.7	20.9	23.8	12.2	21.6	83.6	20.8	0.60	0.46	0.51	0.32
Mean	3.8	1.3	0.38	35.3	23.8	24.8	14.3	19.8	82.7	23.8	0.69	0.48	0.58	0.34

²Abbreviations are defined in Table 2.

cultivars, 'Hech Ben Smail' (T2) and 'Abiod' (T1) from Tunisia, 'Tuono' (I3) and 'Cristomorto' (I2) from Italy, 'Ai' (F1) from France, and 'Burbank' (U1) from the U.S (Fig. 2). The U.S. cultivar 'Mission' ('Texas') (U2) had a highly negative component for PC1, a positive coordinate for PC2, and clusters with 2 Moroccan selections 'Bualuzen' (8A) and 'B2/S7' (1E) (Fig. 2). All were characterized by small nut and kernel length, weight and width, thick nuts and kernels, and long petioles (Table 4, Appendices 2 & 3). 'Bualuzen' (8A) and 'B2/S7' (1E) are from 2 different survey areas separated by 400 kilometers . Three Moroccan selections, 'B2/S11' (1G), 'B1/S15' (1C), and 'Messaoud' (8B), loaded on the negative end of PC1 and PC2 (Fig. 2). These clones represented low values for kernel weight, thickness, and size, and high values for kernel ratio 3 which loaded negatively on PC1 (Table 4, Appendices 1 & 2). 'B2/S11' (1G) and 'B1/S15' (1C) are from the Errachidia region, while 'Messaoud' (8B) is from Meknes region, two regions of survey about 400 km apart (Fig. 1).

At Station #2, forty six selections and introduced cultivars were studied (Table 1).

The first 3 PC's accounted for 58.2 % of the total cumulative variance with PC1, PC2, and PC3 accounting for 26.8% , 16.3%, and 15.1%, respectively. Nine nut and kernel variables loading highly on PC1 were, in descending order of importance, nut size, nut width, kernel size, nut weight, kernel width, nut length, nut thickness, kernel weight, and

kernel length (Table 3). On PC2, 6 leaf characteristics had high positive loadings (Table 3), and were, in descending order, total leaf length, blade length, leaf area, leaf width, petiole length, and gland number. On PC3, 4 different nut and kernel ratios (Table 3) were important, in descending order: nut width/nut length, nut thickness/nut length, shell hardness (kernel weight/nut weight), and kernel width/kernel length. The only trait that loaded negatively was shell hardness. Kernel length loaded on absolute value slightly higher on PC3 than PC1, but its value was negative on PC3 (- 0.32) while positive on PC1 (0.27).

'Ighri/13' (6B) is an outlier and falls separately on the positive end of PC1 (Fig. 3). This genotype is from Taliouine, the area closest to Atlantic Ocean. It had the highest nut and kernel values (Table 5). Omitting 'Ighri/13' (6B), the plot of the selections and cultivars does not indicate any clearly defined groups. However, except for the Italian cultivar 'Cristomorto' (I2), all the introduced cultivars at Station #2, plus 'Cristomorto' x 'Ardechoise' hybrid (M1) and the Moroccan natural peach-almond hybrid (M2) were located on the positive end of PC2, while Moroccan selections had coordinates toward the negative end of PC2 (Fig. 3), indicating that Moroccan selections were characterized by small leaf traits (Table 5). The Spanish cultivar 'Marcona' (S1), was on the positive end of PC3, characterized by nut and kernel values lower than average, particularly nut and kernel length,

Fig. 3: Position of PC scores of introduced cultivars and Moroccan selections. Station #2.

Alphanumericals inside signs are abbreviations of trees and the first digit refers to the country or area of origin (Table 1). Circles - clones. Diamonds - cultivars. Squares - hybrids.

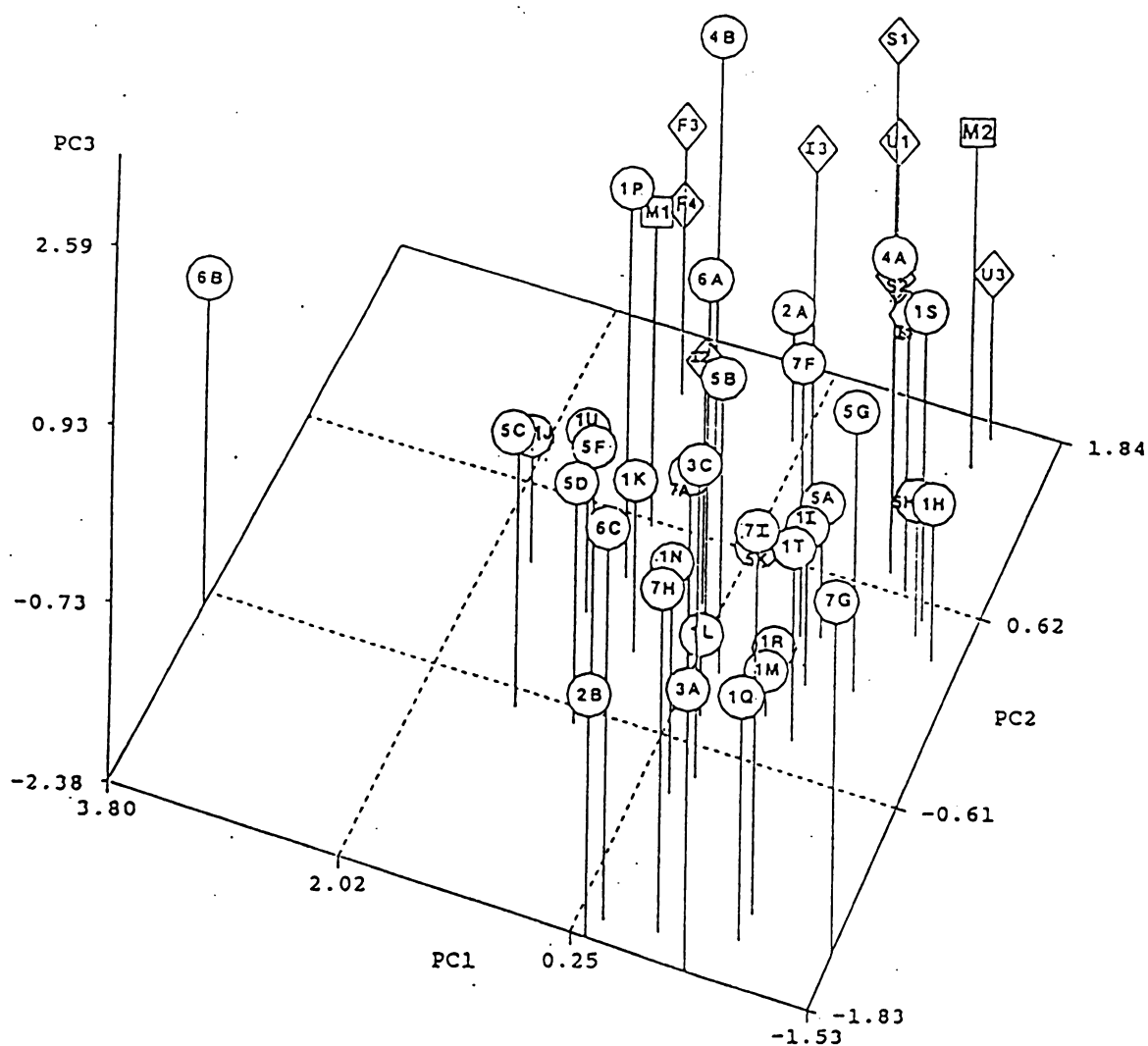


Table 5: Means of representative characters highly loading on PC1, PC2, and PC3 axes for Figure 3 (Station # 2).

Clone	NWT ²	KWT	SH	NL	NW	KL	KW	PETL	BL	BW	NR1	NR2	KR1
Ferragnes	5.1	1.6	0.30	37.6	28.8	27.8	18.3	21.8	97.4	35.2	0.78	0.49	0.72
Crist. X Ard.	5.1	1.6	0.31	38.1	28.1	24.9	16.8	26.6	86.6	28.8	0.73	0.48	0.67
Cavaliera	2.3	1.3	0.56	27.0	20.4	22.2	13.9	21.8	95.4	27.6	0.75	0.59	0.62
Burbank	2.5	1.2	0.48	28.7	22.4	22.2	13.7	28.0	90.8	31.4	0.77	0.59	0.61
Desmayo	3.8	1.1	0.29	33.1	21.3	23.9	12.4	24.8	101.8	24.4	0.64	0.42	0.51
Marcona	4.2	1.0	0.23	25.5	23.5	18.9	13.6	29.4	96.8	23.0	0.95	0.70	0.73
Tuono	3.2	1.2	0.38	32.2	24.9	22.3	15.1	24.8	94.6	27.0	0.77	0.52	0.67
Fournat	4.0	2.3	0.57	41.5	25.1	31.8	19.5	26.0	103.5	29.0	0.60	0.34	0.61
Cristomorto	4.7	1.4	0.30	37.2	25.7	24.3	15.5	18.3	86.3	31.0	0.69	0.46	0.63
Thompson	1.8	1.3	0.74	28.6	17.4	23.8	13.8	28.3	99.5	29.6	0.60	0.42	0.58
AxP/66	5.6	0.6	0.10	30.0	23.0	18.1	11.7	15.2	114.4	36.6	0.77	0.58	0.64
B2/25R	5.6	2.9	0.53	41.6	26.7	26.6	16.3	19.0	90.5	25.0	0.64	0.45	0.61
B2/22R	2.7	1.5	0.55	35.4	23.8	26.6	14.6	17.0	73.8	21.8	0.67	0.47	0.31
B1/6BL	4.1	1.3	0.31	30.0	23.8	23.0	14.5	10.8	66.6	24.0	0.79	0.57	0.36
B2/14R	2.9	1.8	0.63	39.9	18.6	31.3	12.2	20.4	87.4	30.6	0.47	0.40	0.32
B2/19R	2.6	1.4	0.50	34.4	21.0	20.5	12.6	22.6	93.0	31.0	0.61	0.43	0.15
B2/11R	2.7	1.3	0.46	32.4	20.4	22.9	12.5	14.8	69.0	20.4	0.62	0.48	0.54
B1/8R	3.0	1.3	0.45	42.0	19.2	29.1	11.7	22.0	84.4	27.8	0.45	0.39	0.40
B1/22R	2.6	1.0	0.40	34.5	21.7	23.6	13.0	20.6	76.8	28.0	0.63	0.48	0.54
B1/7R	3.4	1.8	0.51	40.1	21.0	29.4	12.8	19.8	80.0	29.3	0.52	0.42	0.43
B1/5R	5.7	1.5	0.26	41.3	23.9	30.0	14.6	27.4	80.0	28.6	0.57	0.44	0.48
B2/8R	6.2	1.7	0.27	35.8	27.8	22.6	16.9	24.0	88.0	24.2	0.77	0.53	0.74
B1/4R	8.7	1.8	0.20	48.3	27.0	32.7	14.5	29.3	82.8	31.5	0.55	0.42	0.44
B1/2L	3.0	2.1	0.70	27.2	18.1	20.9	11.7	21.8	80.2	33.6	0.66	0.54	0.56
B1/6BL	2.7	1.5	0.56	31.5	20.2	26.3	13.5	17.8	82.2	29.8	0.64	0.47	0.51
Hart/16	4.1	2.4	0.59	37.3	25.0	26.4	14.6	21.5	101.0	31.8	0.67	0.43	0.55
Hart/17	5.1	1.5	0.29	36.4	22.9	26.9	13.8	15.4	62.6	22.6	0.62	0.50	0.51
Khorbat/3J	4.2	1.1	0.26	32.8	21.3	22.8	13.6	13.0	67.4	18.8	0.65	0.47	0.59
Tizoug./5R	4.5	1.3	0.29	33.6	23.3	22.3	14.6	20.8	74.4	25.8	0.69	0.54	0.65
Kelaa/5R	3.5	0.9	0.25	30.3	21.0	20.7	13.1	24.4	95.4	25.2	0.69	0.50	0.63
Kelaa/7R	6.5	1.5	0.24	33.9	27.3	22.7	15.9	27.0	98.0	30.0	0.80	0.61	0.69
Skoura/2	2.3	1.4	0.59	35.5	21.1	24.6	13.8	17.5	88.3	28.9	0.59	0.41	0.56
Tiliwine/8V	3.2	1.6	0.49	34.8	21.0	26.2	14.2	16.0	83.4	25.8	0.60	0.43	0.54
Tiflit/2R	6.0	1.5	0.25	41.3	26.8	27.3	15.6	20.8	74.8	24.2	0.65	0.43	0.57
Toundout/3J	2.8	0.8	0.26	29.8	20.3	21.8	13.1	26.0	79.0	26.6	0.68	0.50	0.60
Toundout/1R	6.6	2.0	0.29	39.2	25.5	26.7	15.9	18.6	80.8	25.8	0.65	0.45	0.59
Toundout/8J	2.0	1.3	0.62	32.5	16.2	24.7	12.4	20.0	98.2	26.2	0.49	0.44	0.50
Amekchoud/1J	4.6	1.5	0.30	33.9	23.1	23.5	14.2	20.0	83.4	28.6	0.68	0.58	0.60
Amekchoud/3J	7.4	1.9	0.26	40.1	27.5	28.6	16.8	15.5	82.0	26.3	0.69	0.50	0.59
Ighri/13	9.9	3.0	0.30	47.8	33.7	32.8	19.1	24.0	76.3	20.3	0.70	0.49	0.57
Ighri/1R	4.8	1.5	0.31	32.7	25.4	22.8	13.6	20.7	86.3	27.3	0.77	0.61	0.59
Ighil Noughou	5.1	1.4	0.27	32.8	23.9	23.8	14.6	16.0	65.2	19.6	0.72	0.55	0.61
Ait Saoun/2V	4.8	1.4	0.29	37.3	24.2	26.4	13.2	17.4	83.2	29.2	0.64	0.49	0.50
Agdz/1BL	3.9	1.3	0.34	30.0	22.5	25.4	14.0	23.2	81.6	29.8	0.77	0.54	0.32
Ircheg/2R	2.8	0.7	0.25	26.7	20.3	18.7	11.9	13.8	68.2	21.8	0.75	0.58	0.63
Tinzouline/3V	2.8	1.2	0.41	26.6	20.9	20.8	14.0	16.2	63.2	20.4	0.78	0.58	0.45
Mean	4.2	1.5	0.39	34.8	23.2	24.8	14.3	20.9	84.7	27.0	0.68	0.50	0.60

² Abbreviations are defined in Table 2.

inducing high nut and kernel ratios (Table 5). On the negative side of PC3 were found two Moroccan selections, 'B1/8R' (1M) and 'B2/14R' (1R), because of their long and small size nuts and kernels (Table 5).

At Station # 3, 37 Moroccan clones and 2 foreign cultivars, 'Tuono' (I3) from Italy and 'Ferragnes' (F3) from France, were studied (Table 1). PC1, PC2, and PC3 represented 56% of total variance with respectively 25.4% , 18.6% , and 11.8% (Table 3). PC1 included variation for 7 nut and kernel traits, which, in descending order of importance, were nut size, nut width, nut weight, nut thickness, kernel width, kernel size, and kernel weight. On PC2 the highly loaded variables were 6 nut and kernel traits (Table 3), mainly nut and kernel ratios, and included, from high to low absolute value: nut thickness/length, kernel thickness/length, kernel length, nut length, nut width/length, and kernel width/kernel length . Nut length and nut width were loaded negatively. Six growth habit traits loaded on PC3 (Table 3). They were from high to low values: number of laterals/1-year-old shoot, number of nodes/1-year-old shoot, number of spurs/cm of 2-year-old shoot, number of spurs/2-year-old shoot, 1-year-old shoot length, and 2-year-old shoot length. The 2 spur variables were loaded positively while vegetative growth variables were loaded negatively, suggesting that 1-year-old shoot growth and growth on 2-year-old shoots were inversely related (Table 6). The leaf traits were of minor importance, only loading on PC5, which

represented 7.9% of the total variance.

Independent clustering groups were not obtained (Fig. 4). 'Kelaa/7R' (4B), the only clone from the Dades region (Fig. 1) was at the extreme positive side of PC1 and PC2 (Fig. 4). It had values above average for all nut and kernel characters (Table 6), including the highest values for nut width and kernel width. On PC2 it was characterized by the highest nut width/length, nut thickness/length, and kernel width/length (2nd value after 'Tinzouline/3V' (7I)).

Nineteen Moroccan selections, 'Tinzouline/3V' (7I), 'Tinzouline/5R' (7J), 'Tamkasselt/3R' (7H), 'Ircheg/2R' (7G), 'Ait Saoun/2V' (7A), 'Ait Saoun/6V' (7D), 'Ait Saoun/S3' (7E), 'Agdz/1BL' (7F), 'Amekchoud/1J' (5B), 'Tiflit/2R' (5D), 'Tiflit/2V' (5E), 'Toundout/1R' (5F), 'Toundout/3J' (5G), 'B1/7R' (1L), 'B1/15R' (1W), 'B1/16R' (1X), 'B2/2R' (1d), 'Khorbat/3J' (3A), and 'Hart/18J' (2C), loaded on the negative side of PC1 and the positive side of PC2 (Fig. 4), and were characterized by small nuts and kernels, high nut and kernel ratios, and a high number of spurs/cm of shoot length, even though shoot growth was variable among selections (Table 6). The first eight selections are from the Draa valley survey region [Ait Saoun, Agdz, Tamkasselt, Tinzouline. (Fig. 1)]. They represent 8 of 10 genotypes tested from this region.

'B1/4R' (1J), 'B1/2R' (1Z), 'B1/1L' (1a) 'B1/4L' (1b), 'B2/19BL' (1e), and 'B2/7R' (1f), were on the negative side of PC2 (Fig. 4) because of their low nut and kernel ratios, due

Alphanumericals inside signs are abbreviations of trees and the first digit refers to the country or area of origin (Table 1). Circles = clones. Diamonds = cultivars.



Table 6: Means of representative characters highly loading on PC1, PC2, and PC3 axes for Figure 4 (Station # 3).

Clone	NWT ²	KWT	NL	NW	KL	KW	LAT	S1L	S2L	SPRS	NR1	NR2	KR1	KR2
Tuono	3.2	1.2	32.2	24.9	22.3	15.1	0.2	17.2	15.0	0.49	0.77	0.52	0.67	0.36
Ferragnes	4.6	1.8	37.8	23.3	28.9	14.5	0.0	11.6	20.8	0.33	0.61	0.45	0.50	0.32
B2/19BL	2.5	0.7	33.2	18.3	22.5	10.2	0.0	10.8	14.3	0.00	0.55	0.42	0.45	0.27
B1/13R	3.1	1.1	34.5	21.3	25.1	12.5	0.0	21.2	14.9	0.19	0.61	0.38	0.49	0.28
B1/15R	2.7	0.9	32.6	20.7	22.8	12.4	0.0	11.4	10.5	0.53	0.61	0.44	0.47	0.31
B1/4R	3.7	1.2	35.3	21.6	25.6	12.2	0.0	9.7	11.1	0.33	0.61	0.44	0.47	0.31
B1/16R	2.6	0.7	27.5	19.8	19.9	11.7	0.0	7.9	12.9	0.27	0.72	0.47	0.58	0.31
B1/17R	2.4	0.9	33.8	22.3	23.6	11.7	0.4	6.8	9.4	0.00	0.66	0.43	0.49	0.28
B2/2R	1.3	0.7	27.3	16.1	19.0	9.5	0.0	22.5	13.7	0.51	0.59	0.46	0.50	0.38
B1/2R	4.2	1.2	34.1	22.7	26.5	13.4	0.8	7.7	11.4	0.30	0.66	0.41	0.50	0.24
B1/1L	2.1	0.9	37.2	19.2	25.1	11.9	0.8	13.8	10.2	0.09	0.51	0.35	0.47	0.23
B1/7R	2.0	0.9	28.6	19.2	20.3	12.6	0.0	8.3	14.7	0.30	0.67	0.54	0.62	0.38
B2/7R	3.3	1.5	37.3	21.9	26.1	13.4	0.0	13.7	11.0	0.27	0.58	0.40	0.51	0.34
B1/4L	3.5	1.2	38.2	19.1	27.1	11.8	0.0	9.0	15.7	0.08	0.48	0.35	0.43	0.26
Hart/18J	2.9	0.8	27.9	20.6	20.6	13.4	0.0	10.2	17.0	0.36	0.73	0.46	0.65	0.32
Khorbat/3J	2.8	0.8	29.6	17.9	20.5	11.5	0.0	20.8	9.4	0.37	0.60	0.45	0.55	0.38
Khorbat/6J	2.8	0.9	28.4	18.6	20.1	10.9	1.2	41.2	36.8	0.03	0.65	0.49	0.54	0.39
Kelaa/7R	5.1	1.5	33.0	28.4	24.5	16.5	2.0	38.1	14.7	0.28	0.85	0.60	0.67	0.34
Amekchoud/1J	3.1	1.0	27.4	19.9	20.1	12.4	0.6	22.6	22.2	0.21	0.72	0.56	0.62	0.41
Amekchoud/3J	5.7	1.3	36.7	25.1	21.9	14.5	1.4	19.2	20.6	0.12	0.68	0.45	0.69	0.36
Tiflit/2V	2.4	0.8	29.2	19.8	21.5	10.5	0.0	7.2	10.7	0.47	0.67	0.50	0.48	0.34
Tiflit/2R	1.9	0.6	23.0	16.6	17.3	10.8	0.0	7.1	17.9	0.38	0.72	0.52	0.62	0.40
Toundout/8J	1.1	0.8	27.8	16.3	21.3	10.4	0.2	19.3	13.6	0.15	0.58	0.39	0.48	0.36
Toundout/3J	2.7	0.9	30.5	19.1	23.5	12.6	0.0	10.4	8.8	0.31	0.62	0.44	0.53	0.32
Toundout/1R	3.7	0.9	31.3	21.5	22.2	13.3	0.0	11.2	11.8	0.43	0.68	0.44	0.60	0.30
Tiliwine/8V	2.6	1.4	34.9	22.0	24.9	13.6	0.0	10.4	11.0	0.28	0.63	0.42	0.54	0.32
Tiliw/8TER	5.4	1.4	40.9	23.4	26.5	15.0	0.2	15.2	12.1	0.18	0.57	0.41	0.56	0.28
Ighri/12B	4.8	1.5	32.1	22.3	25.0	14.2	0.0	16.6	10.2	0.45	0.69	0.49	0.56	0.35
Ighri/13B	5.1	1.6	34.6	24.4	25.0	15.8	0.4	13.2	9.9	0.26	0.70	0.47	0.63	0.34
Ait Saoun/2V	2.0	1.1	32.5	18.3	24.3	11.8	0.0	8.8	8.4	0.66	0.56	0.42	0.48	0.33
Ait Saoun/4V	3.5	1.3	34.8	22.4	24.8	13.0	0.0	21.1	12.1	0.05	0.64	0.43	0.52	0.33
Ait Saoun/5V	4.8	1.5	31.8	24.3	24.0	14.4	0.0	17.2	13.0	0.10	0.76	0.61	0.60	0.41
Ait Saoun/6V	2.1	1.0	29.1	18.5	22.5	11.3	0.0	8.3	8.9	0.40	0.63	0.47	0.50	0.36
Ait Saoun/S3	2.5	0.6	26.3	17.7	19.3	11.2	0.0	5.2	10.0	0.63	0.67	0.53	0.58	0.34
Agdz/18L	2.8	0.8	29.9	19.3	21.8	12.2	0.0	7.4	9.2	0.46	0.64	0.43	0.56	0.32
Ircheq/2R	3.6	0.9	28.8	21.5	20.0	13.4	0.4	14.0	13.6	0.20	0.74	0.54	0.65	0.36
Tamkasselt/3R	3.5	1.1	29.7	22.8	21.9	12.8	0.0	16.9	11.8	0.34	0.76	0.54	0.58	0.40
Tinzouline/5R	3.6	1.0	30.2	23.3	19.7	12.9	0.0	17.0	16.5	0.44	0.77	0.54	0.65	0.42
Tinzouline/3V	2.8	1.0	26.7	23.0	21.2	15.6	0.0	8.1	12.3	0.51	0.85	0.56	0.77	0.38
Mean	3.2	1.1	31.7	21.0	22.8	12.8	0.2	14.3	13.5	0.30	0.67	0.47	0.56	0.34

² Abbreviations are defined in Table 2.

to their long nuts and kernels (Table 6). All these selections are from the Errachidia area of survey (Fig. 1).

The 'Ferragnes' (F3) cultivar from France and 'Tuono' (I3) cultivar from Italy, plus 5 Moroccan selections 'Ighri/12B' (6D), 'Ighri/13B' (6E), 'Amekchoud/3J' (5C), 'Tiliouine/8TER' (5L), and 'Ait Saoun/5V' (7C), loaded positively on PC1 and PC3 (Fig. 4), and were characterized by high nut and kernel weights, with a tendency to large nuts and kernels (Table 6). 'Tuono' and 'Ferragnes' had vigorous shoot growth and high spur production, while Moroccan selections with vigorous shoot growth had low spur production [i.e., 'Amekchoud/3J' (5C) and 'Ait Saoun/5V' (7C)] (Table 6). Other remaining selections of the group, excluding 'Ighri/12B' (6D) had average shoot growth and a tendency to low spur production (Table 6).

'Khorbat/6J' (3B) had the most negative value on PC3 (Fig. 4) because of its highest values for the number of laterals and for 1 and 2-year-old shoot growth, and its low spur number (Table 6).

About one third of the selections at Station 3 had better or equivalent spur production potential relative to foreign cultivars. Among these, 'Ait Saoun/2V' (7A), 'Ait Saoun/S3' (7E), 'B1/15R' (1W), 'B2/2R' (1d), 'Tinzouline/3V' (7I), 'Tiflit/2V' (5E), and 'Ighri/12B' (6D) showed high spur production. However, all of these selections, except 'Ighri/12B' (6D), had small nuts and kernels.

CONCLUSION:

Nut and kernel, leaf, and growth habit traits that were consistently highly loaded on the three principal axes at the three stations were nut and kernel weight, nut and kernel sizes, explained, respectively, by high loading of nut length and width, and kernel length and width, nut and kernel width/length and thickness/length s, blade length, blade width, petiole length, total leaf length, leaf area, one and two-year-old shoot length, number of laterals and number of nodes/cm on 1-year-old shoots, number of spurs/2-year-old shoot, and number of spurs/cm on 2-year-old shoots. Nut and kernel measurements were always highly loading on PC1, and nut and kernel ratios on PC2, except for Station 2 where they loaded on PC3. When growth habit was not considered, leaf traits loaded either on PC2 or PC3. Growth habit traits loaded on PC3 at Station 3. For all 3 analyses, nut and kernel traits always explained the largest portion of the variance, indicating that these traits were more variable than growth habit and leaf traits. Growth habit traits, measured at Station 3 only, were more important than leaf traits in explaining variation among the selections.

Station 1, which had the largest number of foreign cultivars (10 cultivars), with cultivars to clone ratio of approximately 1:1, presented greater differences among trees in the morphological traits studied than the other stations.

From this morphological study, there was no evidence that

Moroccan almond ecotypes exist in this collection, since clones did not cluster by survey area. The absence of separate ecotypes could be explained by the fact that all surveyed areas, as shown in Fig. 1, are on the main southern road connecting the east and the west of the country and that seeds were spread by continuous population flow within the survey axis. However, at Station 3, most of the selections from the Draa Valley were characterized by small nuts and kernels and high spur production and clustered together. The Draa valley separates from the main east-west axis at Ouarzazate toward the south, and population flow is less important there. At Station 3 also, most of the selections from Errachidia survey area, south east of Morocco, clustered together, and were characterized by long nuts and kernels.

Some foreign cultivars, even though clustering with Moroccan clones and other cultivars, remained grouped with respect to their country of origin. Most foreign cultivars were distinguished from the majority of the Moroccan selections by larger leaves and softer shells (kernel weight/nut weight). The tendency of Moroccan clones to have small leaves and petioles could have resulted from natural selection for resistance to drought conditions. In most surveyed areas, almond trees are rarely irrigated. Hard shells have been selected by the Moroccan growers to prevent insect damage during storage. Almond is preferred to other fruit crops because it is not a perishable commodity and there are

no special conditions for storage when it has hard shells. Except for tendencies toward small leaves and hard shells, nut and kernel characteristics were highly variable ranging from nut and kernels with characteristics better or similar to good foreign cultivars to small nut and kernels with little commercial value.

In summary, although the morphological variation observed among Moroccan selections did not suggest the existence of separate ecotypes, morphological differences were identified between Moroccan selections and introduced cultivars. Eleven clones were identified that are presumably adapted to dry conditions with good nut and kernel quality ['Ighri/13' (6B), 'Ighri/12B' (6D), 'B2/25R' (1U), and 'Kelaa/7R' (4B)] and/or have good yield potential ['Ait Saoun/2V' (7A), 'Ait Saoun/S3' (7E), 'B1/15R' (1W), 'B2/2R' (1d), 'Tinzouline/3V' (7I), 'Tiflit/2V' (5E), and 'Ighri/12B' (6D)). These selections could be used as parents in a breeding program, or directly as new cultivars.

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**Appendix 1: Means of characters measured highly loading
on PC1 axis for Figure 2 (Station # 1).**

Clone	NL	NW	KL	KW	KWT	NVOL	KVOL	KR3 ²
Marcona	33.6	30.3	23.5	17.5	1.6	22454	3652	0.51
Cristo.	34.8	23.4	23.3	14.6	1.1	13040	2348	0.47
Tuono	32.4	24.8	22.9	14.6	1.1	13276	2537	0.52
AI	32.3	25.1	26.0	15.6	1.4	13054	3212	0.51
Ardech.	51.6	24.9	29.7	15.8	1.7	18414	3395	0.46
Fournat	40.4	27.3	30.5	16.6	2.0	18999	4055	0.48
Burbank	41.6	26.0	28.7	15.1	1.7	19850	3870	0.59
Mission	25.7	19.9	19.6	12.9	1.2	8627	2825	0.84
Abiod	31.6	23.7	23.5	14.9	1.2	11602	2538	0.48
Hech.	32.5	24.6	24.5	15.5	1.4	13425	2889	0.49
KsarSouk	33.7	24.5	23.9	13.8	1.3	13019	2662	0.59
Bualuzen	30.0	22.6	21.8	13.4	1.2	11938	2680	0.68
Messaoud	37.9	21.3	24.3	11.7	1.1	12078	2277	0.68
B2/S7	29.1	21.4	20.9	12.6	1.1	11133	2429	0.72
B1/S2	38.5	24.7	28.2	14.7	1.5	17607	3212	0.53
B1/S17	42.7	25.5	28.2	15.1	1.6	18471	3642	0.56
B2/S9	37.9	22.9	26.6	14.0	1.4	14228	3148	0.61
B2/S11	30.0	19.1	21.0	11.2	0.8	7828	1807	0.68
B1/S15	34.7	20.9	23.8	12.2	1.0	11534	2201	0.63
Mean	35.3	23.8	24.8	14.31	1.3	14242	2917	0.58

²Variable loading negatively on PC1.

**Appendix 2: Means of characters measured highly loading
on PC2 axis for Figure 2 (Station # 1).**

Clone	FR1	FR2	KR1	KR2	KTH	PETL
Marcona	0.90	0.66	0.75	0.38	8.92	29.4
Cristomorto	0.67	0.46	0.63	0.29	6.82	18.0
Tuono	0.77	0.51	0.64	0.33	7.58	24.8
Ai	0.78	0.50	0.60	0.51	7.94	12.4
Ardechoise	0.48	0.28	0.53	0.25	7.26	23.6
Fournat	0.66	0.43	0.55	0.48	7.98	23.6
Burbank	0.63	0.44	0.53	0.59	8.92	24.4
Mission	0.78	0.64	0.66	0.84	10.84	23.2
Abiod	0.75	0.49	0.64	0.48	7.22	9.6
Hech B.Smail	0.76	0.52	0.63	0.49	7.60	23.2
Ksar Souk	0.73	0.47	0.58	0.34	8.06	23.4
Bualuzen	0.75	0.58	0.62	0.42	9.12	23.6
Messaoud	0.56	0.40	0.48	0.33	7.96	10.2
B2/S7	0.73	0.61	0.60	0.43	9.08	21.6
B1/S2	0.64	0.48	0.52	0.28	7.76	14.8
B1/S17	0.60	0.40	0.54	0.30	8.44	14.2
B2/S9	0.61	0.43	0.53	0.32	8.56	17.4
B2/S11	0.64	0.45	0.54	0.36	7.64	17.0
B1/S15	0.60	0.46	0.51	0.32	7.58	21.6
Mean	0.69	0.48	0.58	0.34	8.17	19.8

Appendix 3: Means of characters measured highly loading
on PC3 axis for Figure 2 (Station # 1).

Clone	BL ²	BW ²	LL ²	LA ²	NWT	NTH	SH
Marcona	96.8	23.0	126.2	2227	7.72	22.06	0.21
Cristo.	84.0	31.4	102.0	2631	3.38	15.92	0.35
Tuono	94.6	27.0	119.4	2554	2.64	16.48	0.42
AI	63.8	18.6	76.2	1195	3.20	16.10	0.45
Ardech.	108.6	26.0	132.2	2824	3.22	14.24	0.53
Fournat	109.2	35.6	132.8	3927	4.88	17.48	0.40
Burbank	85.0	20.4	109.4	1734	3.44	18.22	0.51
Mission	90.2	23.6	113.4	2139	2.70	16.54	0.46
Abiod	79.6	22.4	89.2	1780	3.20	15.46	0.38
Hech.	85.6	24.8	108.8	2137	2.68	16.78	0.52
Ksar Souk	79.4	22.4	102.8	1786	5.02	15.76	0.25
Bualuzen	84.2	26.4	107.8	2241	2.82	17.54	0.43
Messaoud	69.8	20.4	80.0	1421	4.82	14.96	0.23
B2/S7	82.8	22.2	104.4	1839	2.64	17.80	0.41
B1/S2	59.0	20.8	73.8	1230	6.32	18.40	0.24
B1/S17	71.2	23.0	85.4	1639	3.86	16.72	0.43
B2/S9	71.2	22.8	88.6	1631	3.40	16.40	0.41
B2/S11	73.6	20.6	90.6	1517	1.78	13.62	0.43
B1/S15	83.6	20.8	105.2	1740	3.80	15.90	0.26
Mean	82.7	23.8	102.5	2010	3.76	16.65	0.38

²Variables loading negatively on PC3.

Appendix 4: Means of characters measured highly loading on PC1 axis for Figure 3 (Station # 2).

Clone	NWT	NL	NW	NTH	KWT	KL	KW	NVOL	KVOL
Ferragnes	5.12	37.62	28.82	17.36	1.62	27.78	18.28	19588	4502
Crist. X Ard.	5.14	38.08	28.08	18.44	1.62	24.90	16.80	19695	4086
Cavaliera	2.28	27.04	20.36	16.18	1.28	22.24	13.88	8914	3072
Burbank	2.48	28.72	22.36	17.00	1.18	22.24	13.66	10949	2818
Desmayo	3.80	33.10	21.28	14.04	1.08	23.90	12.40	10004	2325
Marcona	4.18	25.54	23.48	17.30	0.96	18.86	13.64	10392	2351
Tuono	3.24	32.16	24.90	16.94	1.22	22.32	15.10	13592	2732
Fournat	3.95	41.45	25.05	14.30	2.25	31.80	19.45	14685	5723
Cristomorto	4.68	37.20	25.70	17.23	1.43	24.28	15.50	16513	3277
Thompson	1.80	28.58	17.38	12.03	1.33	23.75	13.83	6081	2743
AxP/66	5.56	29.58	23.00	17.18	0.58	18.12	11.72	11729	1454
B2/25R	5.63	41.63	26.73	19.05	2.88	26.60	16.28	21585	3539
B2/22R	2.70	35.36	23.84	16.68	1.50	26.62	14.58	14081	3223
B1/68L	4.08	30.04	23.80	17.20	1.26	22.98	14.54	12329	2837
B2/14R	2.90	39.84	18.56	16.02	1.84	31.32	12.18	11869	3918
B2/19R	2.64	34.44	21.04	14.98	1.36	20.47	12.58	10898	2145
B2/11R	2.68	32.42	20.38	15.80	1.26	22.86	12.50	10601	3014
B1/8R	2.96	41.96	19.18	16.38	1.34	29.10	11.74	13199	2979
B1/22R	2.56	34.46	21.68	16.64	1.02	23.62	12.98	12464	2233
B1/7R	3.43	40.08	21.00	17.05	1.78	29.40	12.75	14443	3697
B1/5R	5.68	41.30	23.88	18.50	1.48	30.02	14.60	18266	3238
B2/8R	6.22	35.78	27.84	19.22	1.72	22.62	16.90	19279	4064
B1/4R	8.65	48.33	26.98	20.73	1.75	32.68	14.53	27165	3717
B1/2L	3.04	27.24	18.08	14.84	2.14	20.90	11.72	7307	1838
B1/68L	2.70	31.54	20.16	14.84	1.54	26.26	13.48	9533	3416
Hart/16	4.13	37.25	25.00	16.05	2.40	26.38	14.60	14942	2852
Hart/17	5.14	36.36	22.88	18.22	1.54	26.88	13.84	15188	3142
Khorbat/3J	4.16	32.80	21.34	15.62	1.12	22.76	13.58	11065	2374
Tizoug./5R	4.52	33.56	23.34	18.14	1.34	22.30	14.58	14318	3167
Kelaa/5R	3.50	30.32	20.98	15.22	0.90	20.74	13.14	9818	1981
Kelaa/7R	6.45	33.90	27.25	20.68	1.53	22.70	15.85	19220	3608
Skoura/2	2.25	35.53	21.08	14.83	1.35	24.63	13.83	11260	3117
Tilliwine/8V	3.24	34.82	20.98	15.20	1.58	26.18	14.22	11266	3208
Tiflit/2R	6.02	41.24	26.84	17.78	1.54	27.34	15.64	19757	3121
Toundout/3J	2.82	29.82	20.32	14.88	0.80	21.80	13.12	9106	2390
Toundout/1R	6.60	39.22	25.54	17.88	1.96	26.68	15.92	17935	3861
Toundout/8J	2.04	32.46	16.22	14.54	1.26	24.72	12.44	7641	2419
Amekchoud/1J	4.60	33.88	23.14	19.64	1.46	23.50	14.18	15419	3195
Amekchoud/3J	7.35	40.12	27.53	19.45	1.85	28.60	16.75	21136	4428
Ighri/13	9.90	47.80	33.73	23.50	3.00	32.83	19.07	38006	7448
Ighri/1R	4.77	32.70	25.43	19.90	1.50	22.80	13.57	16531	3524
Ighil Noughou	5.12	32.84	23.90	18.20	1.42	23.80	14.56	14417	3400
Ait Saoun/2V	4.80	37.32	24.22	18.54	1.42	26.36	13.24	16864	3301
Agdz/1BL	3.86	30.00	22.46	15.74	1.34	25.36	14.04	10662	2964
Ircheg/2R	2.76	26.68	20.26	15.46	0.70	18.66	11.88	8449	1493
Tinzouline/3V	2.82	26.62	20.90	15.60	1.16	20.80	14.04	8672	2776
Mean	4.23	34.75	23.19	16.98	1.49	24.81	14.30	14279	3189

Appendix 5: Means of characters measured highly loading
on PC2 axis for Figure 3 (Station # 2).

Clone	BL	BW	PETL	LL	GMBRE	LA
Ferragnes	97.40	35.20	21.80	119.20	4.20	3427
Crist.x Ard.	86.60	28.80	26.60	113.20	3.60	2500
Cavaliera	95.40	27.60	21.80	117.20	3.20	2632
Burbank	90.80	31.40	28.00	118.80	6.80	2856
Desmayo	101.80	24.40	24.80	126.60	4.40	2486
Marcona	96.80	23.00	29.40	126.20	3.80	2227
Tuono	94.60	27.00	24.80	119.40	5.20	2554
Fournat	103.50	29.00	26.00	129.50	5.50	3006
Cristomorto	86.25	31.00	18.25	104.50	3.00	2671
Thompson	99.50	29.25	28.25	127.75	5.25	2910
AxP/66	114.40	36.60	15.20	129.60	1.80	4210
B2/25R	90.50	25.00	19.00	109.50	1.75	2267
B2/22R	73.80	21.80	17.00	90.80	3.40	1624
B1/68L	66.60	24.00	10.80	77.40	2.00	1601
B2/14R	87.40	30.60	20.40	107.80	3.80	2722
B2/19R	93.00	31.00	22.60	115.60	3.20	2857
B2/11R	69.00	20.40	14.80	83.80	1.80	1415
B1/8R	84.40	27.80	22.00	106.40	2.40	2363
B1/22R	76.80	28.00	20.60	97.40	3.20	2150
B1/7R	80.00	29.25	19.75	99.75	3.25	2337
B1/5R	80.00	28.60	27.40	107.40	2.60	2285
B2/8R	88.00	24.20	24.00	112.00	4.20	2123
B1/4R	82.75	31.50	29.25	112.00	3.50	2609
B1/2L	80.20	33.60	21.80	102.00	3.20	2715
B1/68L	82.20	29.80	17.80	100.00	3.20	2450
Hart/16	101.00	31.75	21.50	122.50	3.25	3210
Hart/17	62.60	22.60	15.40	78.00	3.20	1432
Khorbat/3J	67.40	18.80	13.00	80.40	1.40	1268
Tizoug./5R	74.40	25.80	20.80	95.20	2.00	1921
Kelaa/5R	95.40	25.20	24.40	119.80	4.80	2419
Kelaa/7R	98.00	30.00	27.00	125.00	5.50	2954
Skoura/2	88.25	28.75	17.25	105.50	3.00	2548
Tiliwine/8V	83.40	25.80	16.00	99.40	3.00	2166
Tiflit/2R	74.80	24.20	20.80	95.60	2.80	1811
Toundout/3J	79.00	26.60	26.00	105.00	3.40	2102
Toundout/1R	80.80	25.80	18.60	99.40	3.40	2084
Toundout/8J	98.20	26.20	20.00	118.20	4.00	2585
Amekchoud/1J	83.40	28.60	20.00	103.40	5.00	2390
Amekchoud/3J	82.00	26.25	15.50	97.50	2.25	2164
Ighri/13	76.33	20.33	24.00	100.33	7.00	1552
Ighri/1R	86.33	27.33	20.67	107.00	5.00	2388
Ighil Noughou	65.20	19.60	16.00	81.20	3.20	1276
Ait Saoun/2V	83.20	29.20	17.40	100.60	4.00	2434
Agdz/18L	81.60	29.80	23.20	104.80	3.40	2445
Ircheq/2R	68.20	21.80	13.80	82.00	2.00	1478
Tinzouline/3V	63.20	20.40	16.20	79.40	4.20	1290
Mean	84.66	27.04	20.86	105.52	3.57	2324

Appendix 6: Means of characters measured highly loading
on PC3 axis for Figure 3 (Station # 2).

Clone	SH	FR1	FR2	FR3	KR1
Ferragnes	0.30	0.78	0.49	0.61	0.72
Cris.x Ard.	0.31	0.73	0.48	0.65	0.67
Cavaliere	0.56	0.75	0.59	0.79	0.62
Burbank	0.48	0.77	0.59	0.76	0.61
Desmayo	0.29	0.64	0.42	0.66	0.51
Marcona	0.23	0.95	0.70	0.73	0.73
Tuono	0.38	0.77	0.52	0.68	0.67
Fournat	0.57	0.60	0.34	0.58	0.61
Cristomorto	0.30	0.69	0.46	0.67	0.63
Thompson	0.74	0.60	0.42	0.69	0.58
AxP/66	0.10	0.77	0.58	0.74	0.64
B2/25R	0.53	0.64	0.45	0.71	0.61
B2/22R	0.55	0.67	0.47	0.69	0.31
B1/68L	0.31	0.79	0.57	0.72	0.36
B2/14R	0.63	0.47	0.40	0.86	0.32
B2/19R	0.50	0.61	0.43	0.71	1.15
B2/11R	0.46	0.62	0.48	0.77	0.54
B1/8R	0.45	0.45	0.39	0.85	0.40
B1/22R	0.40	0.63	0.48	0.76	0.54
B1/7R	0.51	0.52	0.42	0.81	0.43
B1/5R	0.26	0.57	0.44	0.77	0.48
B2/8R	0.27	0.77	0.53	0.69	0.74
B1/4R	0.20	0.55	0.42	0.76	0.44
B1/2L	0.70	0.66	0.54	0.82	0.56
B1/68L	0.56	0.64	0.47	0.73	0.51
Hart/16	0.59	0.67	0.43	0.64	0.55
Hart/17	0.29	0.62	0.50	0.79	0.51
Khorbat/3J	0.26	0.65	0.47	0.73	0.59
Tizoug./5R	0.29	0.69	0.54	0.77	0.65
Kelaa/5R	0.25	0.69	0.50	0.72	0.63
Kelaa/7R	0.24	0.80	0.61	0.75	0.69
Skoura/2	0.59	0.59	0.41	0.70	0.56
Tiliwine/8V	0.49	0.60	0.43	0.72	0.54
Tiflit/2R	0.25	0.65	0.43	0.66	0.57
Toundout/3J	0.26	0.68	0.50	0.73	0.60
Toundout/1R	0.29	0.65	0.45	0.70	0.59
Toundout/8J	0.62	0.49	0.44	0.90	0.50
Amekchoud/1J	0.30	0.68	0.58	0.84	0.60
Amekchoud/3J	0.26	0.69	0.50	0.71	0.59
Ighri/13	0.30	0.70	0.49	0.69	0.57
Ighri/1R	0.31	0.77	0.61	0.78	0.59
Ighil Nougou	0.27	0.72	0.55	0.76	0.61
Ait Saoun/2V	0.29	0.64	0.49	0.76	0.50
Agdz/1BL	0.34	0.77	0.54	0.70	0.32
Ircheg/2R	0.25	0.75	0.58	0.76	0.63
Tinzouline/3V	0.41	0.78	0.58	0.74	0.45
Mean	0.39	0.68	0.50	0.74	0.60

**Appendix 7: Means of characters measured highly loading
on PC1 axis for Figure 4 (Station # 3).**

Clone	NWT	NW	NTH	KWT	KW	NVOL	KVOL
Tuono	3.24	24.90	16.94	1.22	15.10	13592	2732
Ferragnes	4.62	23.32	17.06	1.76	14.46	15099	3920
B2/19BL	2.52	18.28	14.02	0.70	10.24	8535	1432
B1/13R	3.06	21.28	13.34	1.10	12.46	9839	2222
B1/15R	2.72	20.70	14.88	0.94	12.40	9940	2093
B1/4R	3.72	21.56	15.64	1.20	12.22	11931	2537
B1/16R	2.60	19.80	13.08	0.70	11.66	7132	1449
B1/17R	2.38	22.32	14.80	0.90	11.72	1135	1877
B2/2R	1.26	16.06	12.60	0.68	9.54	5535	1314
B1/2R	4.16	22.74	14.24	1.16	13.36	11095	2345
B1/1L	2.12	19.18	13.16	0.86	11.94	9402	1840
B1/7R	1.98	19.24	15.64	0.92	12.64	8758	2001
B2/7R	3.26	21.86	15.22	1.48	13.44	12414	3142
B1/4L	3.48	19.14	13.88	1.22	11.76	10441	2327
Hart/18J	2.86	20.64	12.98	0.82	13.40	7516	1826
Khorbat/3J	2.78	17.86	13.50	0.84	11.48	7210	1885
Khorbat/6J	2.84	18.60	14.02	0.86	10.90	7503	1716
Kelaa/7R	5.12	28.36	20.12	1.52	16.54	18906	3464
Amek./1J	3.10	19.88	15.34	0.96	12.44	8416	2071
Amek./3J	5.68	25.06	16.56	1.26	14.54	15233	2450
Tiflit/2V	2.36	19.76	14.80	0.78	10.52	8558	1694
Tiflit/2R	1.90	16.62	12.12	0.56	10.84	4656	1293
Toundout/8J	1.10	16.30	10.92	0.78	10.40	4961	1702
Toundout/3J	2.66	19.12	13.56	0.92	12.64	7938	2210
Toundout/1R	3.74	21.46	14.04	0.94	13.34	9490	2030
Tiliwine/8V	2.64	22.02	14.84	1.42	13.60	11538	2988
Tiliw./8TER	5.36	23.36	16.96	1.36	15.00	16151	3015
Ighri/12B	4.84	22.28	15.96	1.46	14.22	11447	3144
Ighri/13B	5.10	24.44	16.42	1.60	15.76	14402	3532
Ait Sao./2V	2.04	18.26	13.76	1.08	11.82	8204	2396
Ait Sao./4V	3.48	22.40	15.20	1.32	12.98	11858	2681
Ait Sao./5V	4.82	24.32	19.58	1.48	14.36	15269	3401
Ait Sao./6V	2.10	18.52	13.86	1.00	11.26	7482	2071
Ait Sao./S3	2.54	17.70	13.98	0.64	11.22	6540	1444
Agdz/1BL	2.78	19.34	13.04	0.84	12.22	7578	1863
Ircheg/2R	3.58	21.50	15.74	0.92	13.14	9752	1899
Tamkas./3R	3.46	22.84	16.02	1.14	12.82	10903	2462
Tinz./5R	3.64	23.26	16.46	0.96	12.86	11597	2131
Tinz./3V	2.76	22.96	15.26	0.96	15.62	9573	2534
Mean	3.19	20.95	14.86	1.06	12.74	10193	2285

**Appendix 8: Means of characters measured highly loading
on PC2 axis for Figure 4 (Station # 3).**

Clone	NR1	NR2	KR1	KR2	NL ²	KL ²	SNBRE
Tuono	0.77	0.52	0.67	0.36	32.16	22.32	6.2
Ferragnes	0.61	0.45	0.50	0.32	37.82	28.86	7.0
B2/19BL	0.55	0.42	0.45	0.27	33.18	22.52	7.0
B1/13R	0.61	0.38	0.49	0.28	34.54	25.12	8.4
B1/15R	0.64	0.46	0.54	0.32	32.60	22.80	7.0
B1/4R	0.61	0.44	0.47	0.31	35.32	25.56	6.4
B1/6R	0.72	0.47	0.58	0.31	27.50	19.86	6.8
B1/17R	0.66	0.43	0.49	0.28	33.84	23.64	7.4
B2/2R	0.59	0.46	0.50	0.38	27.32	19.00	6.8
B1/2R	0.66	0.41	0.50	0.24	34.12	26.54	7.4
B1/1L	0.51	0.35	0.47	0.23	37.16	25.08	7.4
B1/7R	0.67	0.54	0.62	0.38	28.60	20.32	7.8
B2/7R	0.58	0.40	0.51	0.34	37.34	26.12	7.8
B1/4L	0.48	0.35	0.43	0.26	38.22	27.12	8.6
Hart/18J	0.73	0.46	0.65	0.32	27.94	20.58	7.8
Khorbat/3J	0.60	0.45	0.55	0.38	29.60	20.48	7.0
Khorbat/6J	0.65	0.49	0.54	0.39	28.40	20.10	7.6
Kelaa/7R	0.85	0.60	0.67	0.34	33.04	24.46	7.2
Amek./1J	0.72	0.56	0.62	0.41	27.40	20.08	7.4
Amek./3J	0.68	0.45	0.69	0.36	36.66	21.94	7.6
Tiflit/2V	0.67	0.50	0.48	0.34	29.20	21.54	7.8
Tiflit/2R	0.72	0.52	0.62	0.40	23.06	17.26	8.2
Toundout/8J	0.58	0.39	0.48	0.36	27.78	21.30	7.2
Toundout/3J	0.62	0.44	0.53	0.32	30.52	23.46	7.4
Toundout/1R	0.68	0.44	0.60	0.30	31.38	22.18	8.0
Tiliw./8V	0.63	0.42	0.54	0.32	34.92	24.88	6.2
Tiliw./8TER	0.57	0.41	0.56	0.28	40.88	26.50	7.2
Ighri/12B	0.69	0.49	0.56	0.35	32.10	25.00	8.2
Ighri/13B	0.70	0.47	0.63	0.34	34.64	24.96	8.2
Ait Sao./2V	0.56	0.42	0.48	0.33	32.50	24.34	7.8
Ait Sao./4V	0.64	0.43	0.52	0.33	34.80	24.76	8.6
Ait Sao./5V	0.76	0.61	0.60	0.41	31.84	23.92	7.2
Ait Sao./6V	0.63	0.47	0.50	0.36	29.08	22.52	6.6
Ait Sao./S3	0.67	0.53	0.58	0.34	26.34	19.34	6.6
Agdz/1BL	0.64	0.43	0.56	0.32	29.92	21.80	7.4
Ircheg/2R	0.74	0.54	0.65	0.36	28.78	20.00	6.8
Tamkas./3R	0.76	0.54	0.58	0.40	29.70	21.88	8.2
Tinz./5R	0.77	0.54	0.65	0.42	30.20	19.72	7.8
Tinz./3V	0.85	0.56	0.77	0.38	26.74	20.16	7.0
Mean	0.67	0.47	0.56	0.34	31.73	22.77	7.5

²Characters loading negatively on PC2.

**Appendix 9: Means of characters measured highly loading
on PC3 axis for Figure 4 (Station # 3).**

Clone	LAT ²	TOTSPRS	S2L ²	S1L ²	SPRS	NODE ²
Tuono	0.2	7.0	15.0	17.2	0.49	1.4
Ferragnes	0.0	6.6	20.8	11.6	0.33	0.0
B2/19BL	0.0	0.0	14.3	10.8	0.00	0.0
B1/13R	0.0	2.8	14.9	21.2	0.19	0.0
B1/15R	0.0	5.6	10.5	11.4	0.53	0.0
B1/4R	0.0	3.8	11.1	9.7	0.33	0.0
B1/16R	0.0	3.4	12.9	7.9	0.27	0.0
B1/17R	0.4	0.0	9.4	6.8	0.00	1.8
B2/2R	0.0	6.8	13.7	22.5	0.51	0.0
B1/2R	0.8	3.0	11.4	7.7	0.30	1.8
B1/1L	0.8	0.8	10.2	13.8	0.09	1.8
B1/7R	0.0	4.4	14.7	8.3	0.30	0.0
B2/7R	0.0	2.8	11.0	13.7	0.27	0.0
B1/4L	0.0	1.4	15.7	9.0	0.08	0.0
Hart/18J	0.0	6.0	17.0	10.2	0.36	0.0
Khorbat/3J	0.0	3.2	9.4	20.8	0.37	0.0
Khorbat/6J	1.2	0.8	36.8	41.2	0.03	6.0
Kelaa/7R	2.0	3.4	14.7	38.1	0.28	1.4
Amek./1J	0.6	4.6	22.2	22.6	0.21	2.6
Amek./3J	1.4	1.6	20.6	19.2	0.12	5.4
Tiflit/2V	0.0	4.6	10.7	7.2	0.47	0.0
Tiflit/2R	0.0	6.6	17.9	7.1	0.38	0.0
Toundout/8J	0.2	2.4	13.6	19.3	0.15	1.6
Toundout/3J	0.0	2.4	8.8	10.4	0.31	0.0
Toundout/1R	0.0	4.8	11.8	11.2	0.43	0.0
Tiliwine/8V	0.0	2.6	11.0	10.4	0.28	0.0
Tiliw./8TER	0.2	2.0	12.1	15.2	0.18	1.6
Ighri/12B	0.0	4.6	10.2	16.6	0.45	0.0
Ighri/13B	0.4	2.6	9.9	13.2	0.26	1.8
Ait Sao./2V	0.0	5.2	8.4	8.8	0.66	0.0
Ait Sao./4V	0.0	0.4	12.1	21.1	0.05	0.0
Ait Sao./5V	0.0	1.8	13.0	17.2	0.10	0.0
Ait Sao./6V	0.0	3.6	8.9	8.3	0.40	0.0
Ait Sao./S3	0.0	6.2	10.0	5.2	0.63	0.0
Agdz/1BL	0.0	4.4	9.2	7.4	0.46	0.0
Ircheg/2R	0.4	2.6	13.6	14.0	0.20	1.8
Tamkas./3R	0.0	4.2	11.8	16.9	0.34	0.0
Tinz./5R	0.0	7.4	16.5	17.0	0.44	0.0
Tinz./3V	0.0	6.2	12.3	8.1	0.51	0.0
Mean	0.22	3.66	13.5	14.3	0.30	0.97

²Characters loading negatively on PC3.

Appendix 10: Eigenvalues of the correlation matrix for the seven first PC's at Station #1.

PC axis	eigenvalue	difference	proportion	cumulative
PC1	8.435	2.343	0.324	0.324
PC2	6.083	2.515	0.234	0.558
PC3	3.567	1.245	0.137	0.695
PC4	2.323	0.577	0.089	0.785
PC5	1.746	0.220	0.067	0.852
PC6	1.526	0.676	0.059	0.910
PC7	0.845	0.300	0.033	0.943

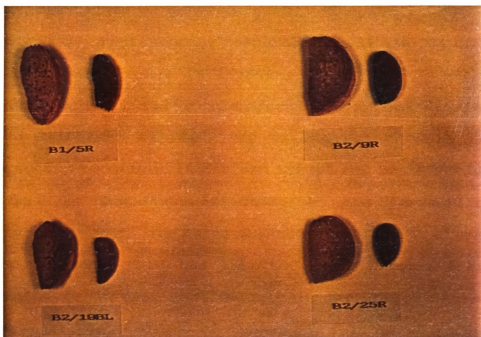
Appendix 11: Eigenvalues of the correlation matrix for the seven first PC's at Station #2.

PC axis	eigenvalue	difference	proportion	cumulative
PC1	6.980	2.745	0.269	0.269
PC2	4.235	0.308	0.163	0.431
PC3	3.927	1.510	0.151	0.582
PC4	2.418	0.365	0.093	0.675
PC5	2.053	0.161	0.079	0.754
PC6	1.892	0.816	0.073	0.827
PC7	1.077	0.093	0.041	0.869

Appendix 12: Eigenvalues of the correlation matrix for the seven first PC's at Station #3.

PC axis	eigenvalue	difference	proportion	cumulative
PC1	8.649	2.309	0.254	0.254
PC2	6.340	2.323	0.187	0.441
PC3	4.017	0.835	0.118	0.559
PC4	3.182	0.515	0.094	0.653
PC5	2.667	0.784	0.078	0.731
PC6	1.883	0.588	0.055	0.786
PC7	1.296	0.034	0.038	0.825

Appendix 13: Almond nuts and kernels of 13 Moroccan selections.



GENERAL CONCLUSION:

Sour cherry Prunus cerasus, commonly known as a self-compatible Prunus species, exhibited gametophytic self-incompatibility by pollen tube growth inhibition in the style. Pollen tube growth and quantity of pollen tubes reaching the ovary suggested the presence of different levels of incompatibility reaction, thus indicating the existence of self-incompatible, partially self-incompatible, and self-compatible cultivars.

Self-incompatibility in Prunus dulcis resulted in the actual genetic variability that exists in different almond producing countries. However, the extensive use of few superior genotypes in breeding programs to improve almond production may reduce the available genetic diversity, and restrict future genetic gain. 'Nonpareil' and 'Mission' cultivars, representing respectively 65% and 25% of commercial almond cultivars in California, are still used extensively as gene sources in California breeding programs. Russian breeders use 'Nikitski 62' cultivar as the major genotype in their breeding programs. In Western Europe and North Africa, Italian cultivars 'Tuono' and 'Cristomorto', and French cultivars 'Ai' and 'Ferragnes' are being extensively used for almond cultivar improvement. This has resulted in increased inbreeding in almond cultivars, particularly in the United States, as well as in varying degrees of coancestry relationships among almond

cultivars in the U.S, Russia, Israel, France and Spain. Germplasm exchange and the use of the same progenitors has led to coancestry relationships among U.S, Russian, and Israeli almond cultivars, and between French and Spanish cultivars.

In North Africa, and particularly in Morocco, almond breeding programs are at their beginning, and almonds are propagated mostly by seedlings, and grown under different environments. As a consequence, genetic diversity may be present and almond ecotypes may have developed. Morphological studies of selected clones of almonds from Southern Morocco and introduced cultivars revealed that Moroccan selections are characterized by small leaves, large fruit variability, and limited fruiting potential. However, some superior Moroccan genotypes were identified. Introduced cultivars had long and wide leaves, and good ratio of shoot growth : yield potential. Even though some Moroccan genotypes from the same area of origin clustered together, there was no evidence of separate ecotypes existing in southern Morocco. The morphological variation observed among genotypes indicates the existence of genetic potential for the development of breeding programs to improve almond production in Morocco.

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