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Genetic Diversity and Heritability of Fruit Traits and Oil Content in Selected Almond Progenies and their Parents

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A R T I C L E I N F O

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A B S T R A C T

Diversity is an essential issue for fruit crop breeding programs and improving selection efficiency. This study was targeted to investigate the genetic diversity and heritability of fruit parameters and oil content in almond progenies and their parents. The results exhibited notable genetic variation among the studied progenies and their parents. The highest phenotypic and genotypic variance (13.05 and 11.18 respectively) was observed in trait of fruit length. . Also the highest broad sense heritability belonged to nut weight of genotype (0.89%). The lowest phenotypic and genotypic variance observed in kernel weight 0.19 and 0.15 respectively, and the lowest broad sense heritability belonged to fruit thickness (0.68%). For oil content, which is important for qualitative improvement in breeding programs, there was a significant difference between examined progenies and their parents. Finally, in this study, it was found that, some of the progenies were high in oil, for example, the hybrid A11-18 had 63.97% of oil that could be used in almond development programs.

Introduction

Almond is one of the most economical nut trees in the world and has high nutritional value. Almond production in the world is 3182902 tons per 2071884 harvest area. Almond production in Iran is 139029 tons per 139029 ha and 4.37 and 7.57 percent of the world's almond production and harvest area, respectively is destined for Iran. In terms of production and harvest area, Iran is ranked third (after the United States and Spain) and fifth (after the Spain, United States, Tunisia and Morocco) (FAO, 2018). Almond is cultivated in the majority of temperate regions of the world but its growth is threatened by late spring frost and other environmental factors (Imani et al., 2021). Therefore, using cultivars with late blooming, higher productivity potential, early fruiting and stability in fruiting, suitable for mechanical harvesting by ease of harvesting and hulling and cultivars with acceptable levels of drought stress tolerance the production costs of the almond industry are reduced (Zokaee-Khosroshahi et al., 2014; Kester *et al.*, 1996; Socias i Company, 1990). In addition, flowering density, yield, fruit ripening time and qualitative traits of fruit are among other important traits in this plant (Kaster and Asay, 1975; Oručević and Aliman, 2018). The phenotype of each plant is affected by its genetic traits and environmental factors. Therefore, it seems that the study of quantitative and qualitative traits of plants along with their genetic information can be useful in doing breeding projects and creation of new cultivars

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with suitable agronomic traits, high of production, better quality and more resistance to environmentally desirable conditions (Burton and Devan, 1953). Almond cultivars vary in size, shape, vigor, branching pattern, growth and bearing habitat, which, as a result of, affects fruiting, pruning needs, training and adaptation to harvest operations (Kester and Assay, 1975; Kodak and Socias i company, 2005; Chalak *et al.,* 2007). To evaluate the cultivars and genotypes based on their quantitative and qualitative characteristics and their relationships, multivariate statistics are required (De Giorgio *et al.,* 2007). The use of multivariate statistics can be very efficient and important, since it clarifies the relationships between dependent and independent attributes (Dicenta F., Garcia, 1992; Karl *et al.,*1998; Sánchez -Pérez *et al.,* 2007; Colic *et al.,* 2012). Lansari *et al*. (1994) have analyzed the factors for the evaluation of morphological diversity of almond cultivars and clones. Their results showed that, the characteristics of nut and kernel in terms of diversity of almond cultivars and clones are more important than leaf characteristics. In another study, 14 genotypes were selected from 1210 apricot hybrid trees, based on flowering duration and fruit quality with the aim of selecting suitable parents for breeding programs. The results showed that the genotypes studied in terms of flowering, soluble solids, acidity and the weight of the fruit was very different (Ebrahimi *et al.,* 2015). Lansari *et al*. (1994) reported that the nut and kernel characteristics in the occurrence of diversity of almond cultivars and clones are more important than leaf characteristics. It is easy to identify the cultivars of Nonpareil, Ne Plus Urltara and Mission. Obtaining the correlation between the growth characteristics of young trees with their structure at the maturity stage allows the breeder to have early decision, especially for subsequent crossings (De Giorgio and Polignano, 2001; Hajnajari et al., 2012). De Giorgio *et al*. (2007) studied 88 almond cultivars in Italy using morphological characteristics. Finally, the cultivars were calssified based on morphological traits in seven distinct groups. Also, Badens *et al*. (1998) evaluated 18 European apricot morphological traits. The diversity observed by them was less than expected. The highest variation was observed in fruit traits. Sarikhani *et al.* (2021) also classified walnut genotypes in Southwest of Iran based on morphological and biochemical traits. Heritability reported high for all nut and kernel traits, ranging from 0.61 for kernel width to 0.79 for in-shell weight. Similar variation of in-shell weight, shell hardness and kernel weight was observed for Nonpareil × Vairo, Nonpareil × Tarraco and Nonpareil × Constantí (Adikari, 2018).

Investigation of almond kernel oil by Socias i Company *et al*. (2008) showed that there was a significant difference between cultivars and genotypes. In this regard, the study was conducted with the aim of achieving the promising genotypes with quantitate and qualitative desirable traits compared to their parents using multivariate statistical analyzes.

Material and Methods

Material Plants

This research was conducted with plant materials including 94 almond hybrids (seven-year-old) with parents of Mamaie and Marcona (conducted as a two-way cross), all of which were the same for all agronomic operations The work was carried out at Meshkin Abad Horticulture Research Station in Karaj (50.9° E, 35. ° 7521 N, 1245 m height, with moderate and cold climates, shallow, calcareous soils, with a pH = 7) during two years, 2017-2018.

Measurement characteristics

Pomological characteristics

Pomological characteristics including flower size, petal length, petal width, sepal length, sepal width, pistil length, pistil thickness, number of stamens, first flowering, 10% flowering, 50% flowering, 90% flowering, flowering period of 33 selected 5 years old almond cultivars and genotypes were evaluated using almond descriptors during 2017 (Gulcan, 1985).

Oil contents

Soxhlet was used to measure oil of almond hybrids with parents of Mamaie and Marcona. In this experiment, at least 2 g almond kernels of each cultivar with 3 replications were done. To do this, first the cut filter paper was put for an hour in the oven; then after 20 minutes it was maintained in the desiccators for the absorption of moisture, and then the dry paper weight was determined with the digital scale. For this purpose, Almond kernel samples of 2 gr of each sample were placed inside a Soxhlet apparatus. The basis of the device was the use of a petroleum ether solvent (250 milliliters). The ground almond kernels were poured into the filter paper and then the samples were put in the oven for 90 minutes. After that they were put in the desiccators for 30 minutes and were weighted with the digital scale (paper and sample weight before the Soxhelt device), then they were placed for a day in the Soxhelt device which was based on the use of Trent Solvent system (Foma and Abdola 1985); therefore, the samples were placed in the vicinity of the air so that their ether is vapoured. Finally, they were put in the oven for 2 hours, and then in the desiccators for 45 minutes. At the end, they were weighted (the weight of the paper and samples after Soxhelt) and their oil percentage was determined according to the method of Foma and Abdola (1985).

$$\text{Oil\%} = \frac{\text{paper weight and sample after soxholder} - \text{Dry paper weight and samplepresoxholder}}{Dry\text{paper weight} - \text{paper weight and samplepresoxh}} * 100$$

Statistical analysis

The data were statistically analyzed based on the analysis of variance in a randomized complete block design. Mean comparison was done by Duncan test at level probality 1 and 5 %.

Multivariate statistics

Multivariate statistics were used to determine the relationships between some important traits using software MSTATC and Excel. Environmental, genotypic and phenotypic variance, general heritability and also phenotypic, genotypic and environmental variation coefficients were calculated using the equations 1-6 (Ansari and Gharaghani, 2019; Pistorale, 2008).

$$V_E = \frac{\text{MSe}}{\text{r}} \quad (1)$$

$$V_G = \frac{\text{MSg}-\text{MSe}}{\text{r}} \quad (2)$$

$$V_{\text{p}} = V_G + V_E \quad (3)$$

$$H_b = \frac{V_G}{V_P} \quad (4)$$

$$CV_P = \frac{\sqrt{V_P}}{\bar{X}} \times 100 \quad (5)$$

$$CV_G = \frac{\sqrt{V_G}}{\bar{X}} \times 100 \quad (6)$$

$$CV_E = \frac{\sqrt{V_E}}{\bar{X}} \times 100 \quad (7)$$

In the above formulas:, V_G, V_E and V_P are genotypic, environmental and phenotypic variance, respectively.

MSg, MSe, r and $\bar{X}$ are treatment variance, error variance, number of replications and mean value. H_b is broad sense heritability, CV_G, CV_P and CV_E are coefficients of genetic, *phenotypic* and environmental variation respectively.

RESULTS

The results showed that the genotype effect on traits such as fruit weight, fruit length, fruit width, fruit thickness, hull thickness, nut weight, nut length, nut width, nut thickness, kernel weight, kernel length, kernel width, kernel thickness and oil percentage are all significant at 1% level (Table 1).

Table 1. Analysis variance for oil content and fruit attributes of selected almond progenies and their parents.

Source	Df	Fruit weight	Fruit length	Fruit width	Fruit thickness	Hull thickness	Nut weight	Nut length	Nut width	Nut thickness	Kernel weight	Kernel length	Kernel width	Kernel thickness	Oil percentage
Genotype	95	22.75**[!]	39.16**	23.50**	15.16**	0.752**	5.79**	30.44**	17.89**	9.20**	0.56**	20.27**	6.82**	8.47**	13.92**
Replication	2	6.02 ns	4.19 ns	5.75 ns	2.13 ns	0.004 ns	0.467 ns	6.88 ns	2.45 ns	5.35 ns	0.030 ns	0.577 ns	0.319 ns	0.59 ns	0.930 ns
Error	190	3.26	5.62	3.69	4.83	0.155	0.660	6.56	2.45	2.87	0.119	2.54	1.47	1.83	0.00
Total	288														

[!] ns, *, and **, respectively, were not significant and significant at 5% and 1% respectively

Considering Table 2, the weight, length, width and thickness of the fruit with hull, in the hybrids examined varied significantly. So that, the highest weight, length, width and thickness of the fruit with hull associated with the hybrids 13-23A, 12-23A, 13-23A and 13-23Awere 24.36 gr, 47.15, 39.27 and 31.36 millimeter respectively. The minimum weight, length, width and thickness of the fruit with hull in the hybrids 11-22A, 11-20A, 11-22A and 11-22A with 5.9 grams, 26.73, 21.12 and 16.83 millimeter. Also, weight, length, width and thickness of nut in the hybrids examined varied significantly. The highest weight, length, width and thickness of the nut associated with the hybrids 12-14A, 11-11A, 13-15A and 13-15A were 9.63 grams, 39.6, 29.04 and 20.46 millimeter respectively. The minimum weight, length, width and thickness of the nut with hull in the hybrids 12-35A, 11-20A, 12-35A and 12-21A with 2.56 grams, 23.43, 16.83 and 12.21 millimeter. On the other hand, the review of Table 1 and 2 indicates that kernel weight, length, width and thickness of the hybrids under study were significantly different. So that the highest the weight, length, width and thickness of the kernel in the hybrids examined varied significantly. The same way, the highest weight, length, width and thickness of the kernel associated with the hybrids 13-51A, 13-51A, 13-15A and 13-46A were 3.06 grams, 33, 18.15 and 16.83 millimeter respectively. The minimum weight, length, width and thickness of the kernel with hull in the hybrids 11-22A, 11-20A, 11-22A and 13-31A with 0.76 grams, 19.14, 9.57 and 6.27 millimeter.

The hybrids were significantly different regarding the mean oil content. The highest total oil content was obtained in hybrid 18-18 A with 63.97%, and the lowest oil content was 29-29 A with 30.06% (Table 2). Estimation of the heritability percentage for the oil content in the hybrids was the intermediate parental level (Fig.1).

The correlation of the studied traits showed that oil percentage is not correlated with other traits. Also, in the remaining cases, traits showed significant correlation at the level of 1% and 5% (Table 3).

Table 2. Mean comparison for oil content and fruit attributes of selected almond progenies and their parents

Cultivar/genotype	Kernel thickness	Kernel width	Kernel length	Kernel weight	Nut thickness	Nut width	Nut length	Nut weight	Hull thickness	Fruit thickness	Fruit width	Fruit length	Fruit weight	Oil percentage
11-11A	6.2700f	14.1900af	29.7000ac	1.46667dj	16.5000ag	23.1000bj	39.6000a	7.43333ah	3.15333bn	20.1300be	27.0600bk	42.2400ae	13.4667bj	49.6124bb
11-12A	6.9300df	12.5400dg	23.4300dk	1.10000gj	15.1800ag	21.4500cl	33.3300ai	5.40000cs	3.00667bn	20.7900be	27.0600bk	37.6200dm	11.7000bk	38.3333bq
11-13A	8.5800bf	12.8700cg	23.4300dk	1.33333dj	12.5400fg	20.7900dl	33.0000aj	4.36667is	2.56667in	19.4700be	24.4200dk	36.6300dm	8.9333fk	50.4202az
11-14A	11.5500bd	13.8600ag	26.0700ch	2.23333ag	16.1700ag	20.7900dl	31.3500ak	4.73333fs	4.29000ad	22.4400be	28.0500bj	36.6300dm	12.3667bj	43.6782bm
11-15A	9.2400bf	14.8500af	23.1000ek	1.53333cj	17.1600ag	24.7500ag	30.6900ak	5.96667co	3.30000an	22.7700ae	29.3700bi	35.6400dm	11.5333bk	59.3220p
11-16A	8.2500bf	15.5100af	23.7600dk	1.53333cj	15.5100ag	24.0900ah	31.3500ak	5.23333cs	3.48333an	22.1100be	28.0500bj	34.9800dn	11.5000bk	54.4304ak
11-17A	7.5900cf	15.5100af	23.1000ek	1.36667dj	17.1600ag	25.4100ae	29.0400ck	5.23333cs	2.64000gn	22.4400be	28.3800bj	32.6700gn	10.3333dk	47.8528bg
11-18A	9.2400bf	12.2100eg	26.0700ch	1.33333dj	14.5200ag	19.4700gl	32.0100ak	4.56667gs	3.00667bn	19.8000be	24.7500ck	32.3400hn	10.0333dk	63.9706a
11-19A	9.9000bf	12.8700cg	19.1400k	1.26667ej	14.5200ag	20.1300el	27.0600fk	3.73333ks	3.11667bn	20.1300be	24.0900ek	30.0300ln	8.1000gk	48.3871be
11-20A	7.9200cf	12.8700cg	19.1400k	0.96667ij	15.5100ag	20.1300el	23.4300k	3.66667ls	2.93333dn	19.1400be	23.1000hk	26.7300n	7.2333ik	60.4396k
11-21A	7.9200cf	15.5100af	23.4300dk	1.33333dj	14.5200ag	21.4500cl	28.3800dk	4.26667is	2.38333mn	18.8100be	24.4200dk	31.0200jn	8.2667gk	43.4343bn
11-22A	6.9300df	9.5700g	21.7800gk	0.76667j	12.2100g	17.1600kl	28.0500dk	2.96667ps	2.67667fn	16.8300e	21.1200k	31.6800in	5.9000k	49.4118bc
11-23A	7.5900cf	13.5300bg	26.4000ch	1.33333dj	15.1800ag	22.7700bj	31.0200ak	4.83333fs	3.15333bn	20.1300be	25.4100bk	33.3300fn	9.5000ek	52.4752as
11-24A	9.2400bf	13.8600ag	21.4500hk	1.53333cj	16.1700ag	21.7800cl	25.0800ik	5.16667cs	3.37333an	21.4500be	26.0700bk	32.3400hn	10.7000bk	55.4140ag
11-25A	8.5800bf	11.5500fg	23.1000ek	1.20000fj	14.1900bg	19.1400hl	29.7000ck	3.03333ps	3.22667an	21.1200be	26.0700bk	34.3200dn	9.3333fk	58.4507s
11-26A	11.5500bd	14.5200af	23.1000ek	1.90000bj	16.1700ag	20.4600el	30.6900ak	5.10000ds	3.04333bn	20.4600be	25.4100bk	33.6600fn	10.0667dk	57.7181u
11-27A	11.5500bd	13.5300bg	27.7200af	2.06667bi	16.8300ag	20.7900dl	33.6600ai	6.43333bl	3.08000bn	22.7700ae	26.4000bk	37.2900dm	12.8000bj	53.2847ap
11-28A	8.9100bf	13.8600ag	24.7500ck	1.56667cj	15.5100ag	22.7700bj	32.3400ak	4.66667fs	2.75000fn	20.1300be	27.7200bk	36.6300dm	9.7667dk	48.9362be
11-29A	8.5800bf	12.2100eg	23.1000ek	1.26667ej	13.5300cg	20.4600el	30.3600bk	3.43333ms	3.48333an	20.4600be	25.7400bk	33.0000fn	9.2667fk	51.3333awax
11-30A	10.2300bf	18.1500a	28.3800ae	2.66667ac	18.4800af	26.4000ac	34.9800ah	7.46667ag	2.97000cn	23.1000ae	31.3500bc	38.2800cl	14.2333bg	43.6782bm
11-31A	9.9000bf	14.5200af	22.7700ek	1.60000cj	17.1600ag	23.1000bj	28.7100ck	5.10000ds	3.00667bn	22.4400be	26.0700bk	32.6700gn	10.1333dk	53.5519ao
11-32A	8.5800bf	13.5300bg	24.4200ck	1.63333cj	14.5200ag	21.4500cl	33.3300ai	4.13333js	2.60333hn	19.1400be	25.7400bk	35.6400dm	9.0000fk	43.3333bo
11-33A	10.5600bf	12.5400dg	23.7600dk	1.73333cj	16.1700ag	22.4400bk	32.0100ak	5.03333es	2.97000cn	20.4600be	25.7400bk	34.6500dn	9.6000dk	45.0438bh
11-34A	10.2300bf	14.8500af	28.3800ae	2.23333ag	19.4700ac	24.4200ah	38.9400ab	7.86667ae	3.08000bn	23.4300ae	28.3800bj	42.5700ad	15.0667bf	51.3661aw
11-35A	8.5800bf	15.8400af	26.0700ch	1.93333bj	15.1800ag	22.7700bj	34.9800ah	4.86667fs	3.33667an	20.7900be	27.7200bk	38.6100bk	11.2667bk	51.0204ax
12-10A	8.5800bf	15.8400af	22.4400fk	1.60000cj	14.8500ag	25.0800af	29.7000ck	5.73333cq	3.15333bn	21.7800be	29.7000bh	34.3200dn	12.0667bk	61.8321f

12-11A	10.8900bf	17.1600ac	22.1100fk	2.06667bi	18.8100ae	26.0700ad	31.0200ak	6.83333aj	3.77667am	25.0800ad	31.0200bd	36.3000dm	14.2667bg	62.3377d
12-12A	9.9000bf	14.1900af	22.1100fk	1.70000cj	19.8000ab	22.7700bj	32.0100ak	4.53333hs	3.59333an	23.1000ae	29.0400bj	36.9600dm	11.7667bk	58.5366r
12-13A	10.2300bf	14.8500af	27.3900bg	1.93333bj	16.8300ag	21.1200cl	34.9800ah	5.33333cs	3.96000ai	21.1200be	26.7300bk	37.9500cm	11.7333bk	43.4343bn
12-14A	7.5900cf	16.8300ad	28.3800ae	1.63333cj	19.1400ad	27.7200ab	37.6200ac	9.63333a	3.00667bn	24.0900ae	31.6800bb	40.9200ag	17.1000b	44.0559bl
12-15A	9.5700bf	13.8600ag	29.0400ad	1.86667cj	15.5100ag	20.1300el	35.3100ag	4.96667es	3.77667am	22.4400be	29.0400bj	38.9400bk	12.5333bj	47.8873bf
12-16A	9.5700bf	14.5200af	27.3900bg	2.03333bi	18.1500ag	24.7500ag	36.3000ae	8.03333ac	3.52000an	23.7600ae	29.0400bj	40.5900ah	15.8000be	57.1429y
12-17A	9.9000bf	15.1800af	22.1100fk	1.66667cj	18.8100ae	22.1100cl	25.0800ik	4.10000js	3.88667ak	23.4300ae	27.7200bk	30.0300ln	10.4000dk	55.4140ag
12-18A	7.2600cf	14.1900af	24.0900ck	1.40000dj	15.5100ag	21.7800cl	32.3400ak	4.33333is	3.15333bn	21.1200be	28.7100bj	35.6400dm	11.3667bk	43.3566bo
12-19A	7.8867cf	13.5300bg	24.4200ck	1.50000cj	16.1700ag	24.7500ag	32.0100ak	5.73333cq	3.19000an	22.4400be	29.0400bj	36.9600dm	13.0000bj	54.2373al
12-1A	8.5800bf	14.8500af	25.0800cj	1.70000cj	16.8300ag	24.7500ag	32.3400ak	6.20000bn	3.00667bn	24.0900ae	29.7000bh	36.6300dm	13.6333bi	55.4745ag
12-20A	10.8900bf	14.8500af	24.7500ck	1.90000bj	16.1700ag	21.4500cl	31.3500ak	5.56667cr	2.82333en	20.4600be	25.4100bk	34.3200dn	10.0767dk	54.3689ak
12-21A	11.5500bd	13.8600ag	25.4100cj	2.20000ah	17.4900ag	22.4400bk	33.9900ai	6.60000bk	4.03333ag	22.7700ae	27.0600bk	37.6200dm	11.8333bk	61.3445h
12-22A	8.5800bf	16.5000ae	22.7700ek	1.53333cj	16.5000ag	24.4200ah	29.0400ck	5.40000cs	2.82333en	20.4600be	27.3900bk	33.0000fn	9.8667dk	50.4000ba
12-23A	9.5700bf	12.8700cg	25.7400ci	1.60000cj	15.8400ag	20.4600el	33.0000aj	5.00000es	3.37333an	22.1100be	25.7400bk	36.9600dm	11.1667bk	53.6585an
12-25A	10.8900bf	14.1900af	24.0900ck	1.93333bj	17.1600ag	22.1100cl	30.0300bk	4.80000fs	4.18000ae	25.0800ad	27.7200bk	34.9800dn	12.3000bk	48.9510bd
12-26A	9.9000bf	12.5400dg	27.7200af	1.73333cj	16.8300ag	21.1200cl	35.9700af	5.80000cp	2.86000en	20.7900be	26.0700bk	38.2800cl	11.6667bk	52.3364au
12-28A	7.9200cf	12.5400dg	22.1100fk	1.23333ej	15.1800ag	21.4500cl	30.0300bk	4.06667js	3.22667an	20.4600be	26.0700bk	33.3300fn	9.4000ek	56.0976ac
12-29A	9.5700bf	13.5300bg	23.7600dk	1.33333dj	14.8500ag	22.7700bj	30.0300bk	4.60000fs	2.93333dn	19.1400be	27.0600bk	33.9900en	9.5000ek	30.0654bs
12-2A	7.5900cf	13.2000cg	19.8000jk	1.06667gj	14.5200ag	22.1100cl	29.3700ck	4.90000fs	2.38333mn	18.8100be	24.4200dk	31.6800in	8.8333fk	50.7042ay
12-30A	10.5600bf	14.1900af	23.1000ek	1.76667cj	17.4900ag	21.4500cl	28.7100ck	5.13333cs	2.27333n	21.4500be	24.4200dk	33.0000fn	9.2667fk	52.7607ar
12-31A	7.5900cf	11.8800fg	22.7700ek	1.06667gj	14.8500ag	19.4700gl	30.0300bk	4.00000js	3.26333an	19.4700be	23.1000hk	33.0000fn	8.6333fk	51.8519av
12-32A	11.8800bc	13.5300bg	25.4100cj	1.93333bj	18.4800af	20.7900dl	32.6700aj	4.16667js	4.36333ac	25.7400ac	28.7100bj	39.2700bj	12.9000bj	53.0435aq
12-33A	9.9000bf	12.8700cg	23.1000ek	1.40000dj	14.8500ag	18.1500jl	31.3500ak	4.23333is	3.19000an	20.1300be	22.4400jk	34.9800dn	9.1667fk	55.6522ae
12-34A	8.5800bf	12.2100eg	22.7700ek	1.23333ej	13.2000dg	19.1400hl	28.3800dk	3.23333os	3.15333bn	18.4800be	23.1000hk	31.3500in	7.1667jk	56.3910ab
12-35A	10.2300bf	11.8800fg	21.4500hk	1.43333dj	14.8500ag	16.8300l	27.7200ek	2.56667s	3.08000bn	20.4600be	22.4400jk	31.0200jn	7.3333ik	61.5385g
12-37A	10.5600bf	13.8600ag	24.4200ck	1.80000cj	17.1600ag	23.7600ai	33.0000aj	4.33333is	4.40000ab	26.0700ab	29.0400bj	37.2900dm	12.3400bk	54.5455aj
12-3A	10.2300bf	15.5100af	25.4100cj	2.16667ah	18.1500ag	25.4100ae	34.6500ah	7.96667ad	3.48333an	24.4200ae	30.0300bg	37.9500cm	16.0000bd	47.7124bg
12-4A	9.2400bf	13.2000cg	20.7900hk	1.23333ej	14.5200ag	20.7900dl	26.0700hk	3.30000ns	3.59333an	20.7900be	26.7300bk	30.6900kn	9.2000fk	54.7170ai

12-5A	8.9100bf	14.5200af	24.7500ck	1.66667cj	16.5000ag	23.4300bj	31.6800ak	5.60000cr	3.66667an	22.4400be	29.0400bj	36.6300dm	12.8333bj	44.1860bk
12-6A	10.5600bf	12.5400dg	26.0700ch	1.66667cj	15.8400ag	19.8000fl	34.6500ah	4.76667fs	3.99667ah	23.1000ae	26.0700bk	38.6100bk	12.9000bj	59.3220p
12-7A	8.2500bf	14.1900af	27.3900bg	1.60000cj	14.8500ag	22.1100cl	37.6200ac	5.86667cp	3.26333an	21.7800be	28.0500bj	42.2400ae	13.1667bj	62.1302e
12-8A	6.5667ef	11.8800fg	24.0900ck	0.93333ij	13.8600bg	18.4800il	30.3600bk	3.96667js	3.30000an	19.1400be	24.0900ek	34.6500dn	8.7667fk	57.4627w
12-9A	8.5800bf	13.2000cg	22.4400fk	1.16667fj	14.5200ag	19.4700gl	26.4000gk	2.86667qs	3.81333al	22.7700ae	28.3800bj	33.6600fn	9.8667dk	43.3333bo
13-10A	8.2500bf	15.8400af	20.7900hk	1.23333ej	13.8600bg	20.1300el	26.4000gk	3.30000ns	4.07000af	20.4600be	27.7200bk	33.3300fn	9.7333dk	53.9326am
13-14A	8.5800bf	12.5400dg	22.7700ek	1.43333dj	15.1800ag	22.4400bk	31.3500ak	4.50000is	2.78667en	19.1400be	23.7600fk	33.0000fn	8.1000gk	56.0000ad
13-15A	11.5500bd	17.1600ac	27.3900bg	2.46667ad	20.4600a	29.0400a	34.6500ah	7.50000af	3.30000an	25.7400ac	31.0200bd	39.6000ai	14.2667bg	56.6265aa
13-16A	10.5600bf	13.2000cg	22.7700ek	1.70000cj	16.1700ag	20.4600el	27.7200ek	4.40000is	3.88667ak	21.1200be	28.7100bj	33.9900en	12.1333bk	59.4595o
13-17A	7.5900cf	13.2000cg	23.1000ek	1.30000dj	13.8600bg	20.1300el	30.6900ak	4.23333is	3.63000an	20.7900be	26.4000bk	35.9700dm	10.5000dk	58.4270s
13-19A	7.0500cf	12.6733dg	24.5533ck	1.56667cj	12.8700eg	18.1500jl	30.6900ak	3.86667ks	2.64000gn	18.1500ce	22.4400jk	34.3200dn	7.6000hk	55.0562ah
13-1A	7.9200cf	15.5100af	24.0900ck	1.63333cj	17.8200ag	25.4100ae	32.0100ak	5.50000cr	3.26333an	24.0900ae	29.3700bi	35.6400dm	12.5333bj	58.5227r
13-21A	8.5800bf	12.2100eg	23.7600dk	1.30000dj	14.1900bg	19.4700gl	31.3500ak	4.46667is	3.26333an	20.1300be	25.4100bk	37.2900dm	8.9333fk	57.7778u
13-22A	8.5800bf	13.8600ag	21.4500hk	1.30000dj	14.8500ag	21.1200cl	28.0500dk	4.30000is	3.22667an	21.1200be	28.7100bj	34.9800dn	10.6333ck	30.2632br
13-23A	11.2200be	15.1800af	29.7000ac	2.40000ae	19.1400ad	25.4100ae	36.3000ae	7.13333ai	4.58333a	30.3600a	39.2700a	47.8500a	24.3667a	63.5220b
13-24A	8.5800bf	13.2000cg	25.4100cj	1.36667dj	14.5200ag	21.1200cl	32.3400ak	4.30000is	2.97000cn	18.8100be	25.0800bk	34.9800dn	7.9333gk	43.2432bp
13-29A	7.5900cf	12.8700cg	23.7600dk	1.23333ej	13.8600bg	20.1300el	33.3300ai	3.80000ks	3.11667bn	19.8000be	25.4100bk	37.6200dm	10.2333dk	57.2368x
13-2A	12.8700ab	14.1900af	26.0700ch	2.30000af	19.4700ac	22.7700bj	30.3600bk	5.43333cs	3.55667an	18.1500ce	26.4000bk	34.6500dn	11.3667bk	54.5455aj
13-31A	6.2700f	12.8700cg	21.1200hk	1.03333hj	14.1900bg	18.1500jl	29.0400ck	4.46667is	2.71333fn	18.4800be	24.4200dk	32.6700gn	9.0667fk	44.7552bj
13-33A	8.2500bf	14.8500af	24.7500ck	1.50000cj	15.8400ag	23.1000bj	32.3400ak	5.76667cq	2.45667ln	20.4600be	29.0400bj	35.9700dm	10.8333bk	59.5238n
13-34A	7.9200cf	13.2000cg	22.7700ek	1.30000dj	14.1900bg	20.1300el	28.3800dk	4.26667is	2.56667in	18.4800be	22.7700ik	31.3500in	8.0667gk	51.2821ax
13-35A	8.5800bf	13.2000cg	22.4400fk	1.40000dj	14.8500ag	20.7900dl	24.0900jk	3.10000os	2.78667en	20.1300be	24.0900ek	31.6800in	8.8667fk	53.6765an
13-39A	8.2500bf	12.8700cg	22.7700ek	1.36667dj	14.5200ag	19.8000fl	28.7100ck	4.33333is	3.59333an	23.1000ae	27.7200bk	33.6600fn	12.0000bk	60.1852l
13-3A	7.5900cf	14.5200af	26.4000ch	1.66667cj	16.8300ag	25.0800af	32.3400ak	6.36667bl	2.89667dn	20.7900be	27.7200bk	35.3100dm	10.6667bk	53.6585an
13-40A	8.5800bf	13.2000cg	27.3900bg	1.56667cj	14.5200ag	21.7800cl	34.9800ah	5.43333cs	3.92333aj	21.7800be	30.3600bf	41.2500af	13.8000bh	58.2857t
13-42A	8.5800bf	14.8500af	22.4400fk	1.43333dj	17.1600ag	25.0800af	30.0300bk	5.13333cs	3.04333bn	21.7800be	27.3900bk	33.6600fn	10.0333dk	44.7853bj
13-43A	7.2600cf	11.5500fg	23.7600dk	1.16667fj	13.8600bg	18.1500jl	31.3500ak	2.73333rs	3.26333an	19.1400be	22.4400jk	33.9900en	7.6333hk	61.1465i
13-46A	16.8300a	12.8700cg	21.7800gk	1.10000gj	15.8400ag	19.8000fl	30.6900ak	4.20000js	2.53000jn	19.8000be	27.1033bk	33.6600fn	8.7000fk	49.5652bc

13-47A	9.2400bf	12.8700cg	21.7800gk	1.43333dj	15.8400ag	20.1300el	28.0500dk	4.16667js	2.97000cn	19.1400be	25.0800bk	31.3500in	8.8333fk	55.5556af
13-49A	6.6000ef	14.1900af	22.7700ek	1.16667fj	14.8500ag	21.4500cl	31.6800ak	5.30000cs	2.82333en	16.8300e	23.7600fk	33.0000fn	7.5667hk	56.8345z
13-4A	8.5800bf	13.5300bg	24.7500ck	1.56667cj	15.1800ag	20.4600el	33.9900ai	4.90000fs	2.60333hn	20.1300be	24.4200dk	36.6300dm	9.3333fk	59.8361m
13-50A	8.5800bf	12.5400dg	25.0800cj	1.46667dj	15.1800ag	19.1400hl	33.6600ai	4.93333fs	2.56667in	18.8100be	22.4400jk	35.9700dm	8.5667gk	5**0ba
13-51A	10.5600bf	18.1500a	33.0000ab	3.06667ab	17.8200ag	27.7200ab	36.3000ae	9.03333ab	3.30000an	24.0900ae	30.6900be	46.2000ac	17.0667bc	52.5000as
13-5A	6.6000ef	14.1900af	26.0700ch	1.26667ej	15.5100ag	21.4500cl	33.9900ai	5.43333cs	2.60333hn	17.4900de	23.1000hk	35.9700dm	7.8333gk	59.1667q
13-6A	10.5600bf	14.1900af	24.7500ck	1.86667cj	17.1600ag	23.7600ai	32.0100ak	6.23333bm	2.38333mn	21.1200be	26.4000bk	33.6600fn	9.3667ek	62.5731c
13-7A	11.8800bc	13.5300bg	25.0800cj	1.86667cj	16.8300ag	20.4600el	33.3300ai	4.20000js	3.37333an	23.1000ae	25.4100bk	36.9600dm	10.1333dk	57.5342v
13-8A	8.9100bf	12.2100eg	24.0900ck	1.40000dj	14.8500ag	20.7900dl	30.3600bk	4.46667is	3.11667bn	20.7900be	27.7200bk	35.3100dm	10.4333dk	62.3529d
13-9A	6.2700f	12.2100eg	20.1300ik	0.83333j	12.2100g	19.8000fl	27.3900ek	3.60000ls	3.08000bn	20.4600be	23.4300gk	31.6800in	7.0667jk	52.4096at
14-1A	10.2300bf	14.5200af	22.7700ek	1.83333cj	17.1600ag	23.4300bj	30.6900ak	4.50000is	3.55667an	19.4700be	30.6900be	38.2800cl	11.0000bk	60.1227l
14-2A	8.2500bf	12.2100eg	22.4400fk	1.26667ej	14.5200ag	19.1400hl	29.7000ck	4.23333is	2.49333kn	18.1500ce	23.1000hk	29.7000mn	8.0000gk	61.3445h
Mamaei	10.9267bf	17.5767ab	33.2333a	3.33333a	18.4867af	26.3900ac	36.9667ad	8.96667ab	3.40000an	25.0900ad	31.3567bc	46.8667ab	17.0667bc	60.8696j
Marconar	11.2300be	13.1900cg	22.7767ek	1.63333cj	16.5033ag	20.7933dl	27.9400dk	4.86667fs	3.91333aj	21.7867be	29.4100bi	34.4900dn	12.3667bj	52.5253as

[!] Means followed by similar letters in each column are not significantly different

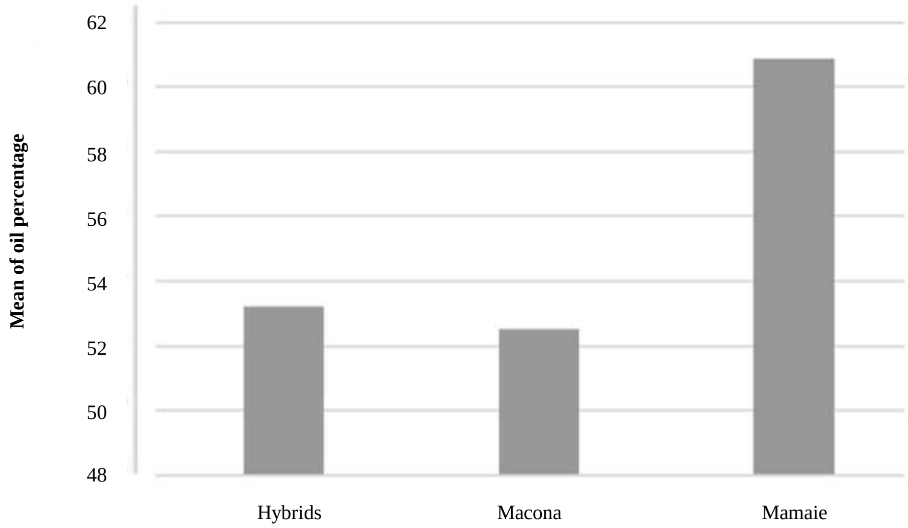

Fig. 1. Mean of oil percentage between Mamaie and Marcona cultivars and hybrids derived from their crossing

Table 3. The correlation of the studied traits

Trait	Oil content (%)	Fruit weight	Fruit length	Fruit width	Fruit thickness	Hull thickness	Nut weight	Nut length	Nut length	Nut thickness	Kernel weight	Kernel length	Kernel width	Kernel thickness
oil content(%)	1													
Fruit weight	0.064ns !	1												
Fruit length	0.047 ns	0.760**	1											
Fruit width	-0.001ns	0.845**	0.625**	1										
Fruit thickness	0.094 ns	0.745**	0.573**	0.692**	1									
Hull thickness	0. 045 ns	0.484**	0.332**	0.482**	0.463**	1								
Nut weight	0.015 ns	0.788**	0.658**	0.619**	0.523**	0.086 ns	1							
Nut length	0.016 ns	0.555**	0.728**	0.393**	0.310**	0.063 ns	0.608**	1						
Nut width	-0.038ns	0.658**	0.466**	0.698**	0.504**	0.112 ns	0.760**	0.419**	1					
Nut thickness	0.059 ns	0.650**	0.411**	0.594**	0.585**	0.303**	0.634**	0.374**	0.633**	1				
Kernel weight	0.088 ns	0.752**	0.603**	0.596**	0.601**	0.305**	0.744**	0.497**	0.597**	0.663**	1			
Kernel length	0.025 ns	0.667**	0.747**	0.461**	0.395**	0.192**	0.695**	0.709**	0.457**	0.419**	0.700**	1		
Kernel width	-0.052ns	0.565**	0.390**	0.604**	0.441**	0.104 ns	0.678**	0.303**	0.730**	0.509**	0.645**	0.417**	1	
Kernel thickness	0.073 ns	0.409**	0.222**	0.351**	0.436**	0.281**	0.312**	0.181**	0.205**	0.525**	0.641**	0.279**	0.253**	1

! ns, *, and **, respectively, were not significant and significant at 5% and 1% respectively

Minimum, maximum, mean, components of variance (phenotypic, genetic and environmental), coefficient of variation and broad sense heritability for 13 almond characteristics are shown in Table 4.

Table 4. Range, standard error, genetic parameters, coefficient of variation and heritability to the studied traits of almond genotypes

Traits	Range		Genotype related to range		StDev	Means	Diversity index	Variance components			Coefficient of variation (%)			Broad sense heritability (%)
	Max	Min	Max	Min				Vp	Vg	Ve	CVp	CVe	CVg	
oil content(%)	64.071	29.965	11-18A	12-29A	6.733	53.295	12.63	4.64	3.58	0.00	23.56	0.00	23.56	0.77
Fruit weight(gr)	31.300	4.300	13-23A	13-19A	3.120	10.839	28.78	7.58	6.50	1.09	5.17	1.96	4.78	0.86
Fruit length(mm)	50.490	23.760	13-23A	13-46A	4.089	35.494	11.52	13.05	11.18	1.87	33.33	12.63	30.85	0.86
Fruit width(mm)	43.560	19.800	13-23A	13-43A	3.204	26.786	11.96	7.83	6.60	1.23	7.89	3.12	7.24	0.84
Fruit thickness(mm)	33.660	9.900	13-23A	13-46A	2.870	21.227	13.52	5.05	3.44	1.61	8.39	4.74	6.93	0.68
Hull thickness(mm)	4.9500	2.2000	12-32A	12-29A	0.5935	3.2123	18.48	0.25	0.20	0.05	2.36	1.07	2.10	0.79
Nut weight(gr)	10.1000	2.1000	13-51A	12-35A	1.5357	5.0233	30.57	1.93	1.71	0.22	43.25	14.60	40.71	0.89
Nut length(mm)	43.580	14.850	Mamaei	13-35A	3.804	31.366	12.13	10.15	7.96	2.19	63.41	29.44	56.17	0.78
Nut width(mm)	30.690	11.880	13-15A	13.31A	2.750	21.859	12.58	5.96	5.15	0.82	7.79	2.88	7.23	0.86
Nut thickness(mm)	26.730	6.930	12-12A	11-13A	2.233	15.878	14.06	3.07	2.11	0.96	8.01	4.47	6.65	0.69
Kernel weight(gr)	3.5000	0.5000	13-51A	13-9A	0.5096	1.5872	32.11	0.19	0.15	0.04	2.72	1.25	2.41	0.79
Kernel length(mm)	35.640	17.820	13-51A	11-19A	2.898	24.273	11.94	6.76	5.91	0.85	163.77	57.97	153.17	0.87
Kernel width(mm)	20.790	8.910	13-10A	11-22A	1.799	13.855	12.98	2.27	1.78	0.49	6.21	2.88	12.86	0.78
Kernel thickness(mm)	16.830	3.960	13-46A	12-18A	2.006	9.145	21.94	2.82	2.21	0.61	12.13	5.64	10.74	0.78

DISCUSSION

Considering Table 1 and 2 the weight, length, width and thickness of the fruit with hull, was significantly different in the examined hybrids . Also the size of the kernel can be related to its longitudinal dimensions, width and thickness. Genetic analysis has shown that heritability for kernel traits such as length, width and thickness was 0.77, 0.62 and 0.71, respectively. The size, shape and weight of the kernel are subject to genetic and horticultural conditions. The average kernel weight is an important factor in determining the yield. Among the almond cultivars, the shape of the kernel can be considered as one of the important components of weight and size. According to the shape of the kernel, we can classify the cultivars for use and type of market (kester *et al.,* 1996). As shown in Fig. 1, the average oil percentage between the hybrids resulting from the intersection of Mamaie and Marcona is intermediate. In other words, the average oil percentage between hybrids is 53%, but in the case of Mamaie and Marcona, 61% and 52% respectively.

Also, there was a significant difference between the mean oil percent in progenies and their parents. Also, the amount of almond oil was ranged from 19.19% to 62% (Mehran and Filsoof, 1974). In another study, the amount of almond oil in the range of 45.9 to 61.7% was determined (Abdallah *et al.,* 1998). In a study of common almond cultivars collected from different areas of California, between 49 and 66 percent of the oilwas reported within two years. In a study (García-López *et al.,* 1996), American cultivar contained 53%- 56% oil, while the oil content of Spanish varieties were 56% (Marcona)- 60% (Ramillet). In this study, oil content among 94 genotypes was considered. Genotype 11-18 was characterized with high oil content in with 63.97%, which make it a good candidate as a breeding genitor for qualitative improvement in almond breeding program. According to Socias i Company *et al*. (2010), the amount of oil in the studied genotypes was influenced by the type of genotype. The difference between the percentage of oil measured in the progenies and their parents indicates the greater role of the genotype. Estimation of the heritability percentage for the oil content in the hybrids was the intermediate parental level (Fig.1), which indicates the very low impact of this trait from environmental factors.

The results of correlation between traits indicated that the weight of the kernel had a significant positive correlation with dry weight of fruit and fruit weight with green skin at 1% level. There was also a significant positive correlation between the weights of the kernel with nut weight. Mousavi *et al*. (2010) evaluated the quantitative and qualitative characteristics of some almond cultivars and genotypes and showed that there was a significant correlation between nut weight and length of kernel. According to the above explanations, the importance of correlation between traits is that it is possible to find out the state of the traits that are difficult to measure, through their correlation with the traits they measure easier. Also, through the correlation between the traits, the traits can be traced to a longer time period, and the plant must necessarily enter the fertility stage, they can be recognized by vegetative traits (Vargas and Romero, 2001).

Coefficient of genotypic diversity is part of the phenotypic variation coefficient; hence its value is always less than the phenotypic variation coefficient. The insignificant difference between the phenotypic and genotypic variation coefficient for the studied characteristics shows that the major part of the existing diversity is due to genetic variation and the environment has little effect. The higher the ratio of genotypic to phenotypic variation, the more selective efficiency and the better known genotypes can be detected from undesired ones (Arab *et al.*, 2020).

Taking into account the results of genotypic, phenotypic and environmental variances associated with genetic diversity, phenotypic diversity coefficient and broad sense heritability presented in Table 4. It is obvious that the genetic variance between genotypes for all of the characteristics measured less than the phenotypic variance. Other characteristics measured in the range of phenotypic variation were 20.58 and 62.7% respectively. For all the measured properties, the phenotypic coefficient of variation was greater than the genetic diversity coefficient. As the phenotypic diversity was greater than genetic diversity, it can be postulated that, the feature is more affected by the environment and the selection efficiency will be low. On the other hand, a slight difference between the genetic and phenotypic variation coefficients for some features, indicates that the genotype has a greater role and less effect of environment on these characteristics. A large part of the phenotypic variation can be caused by the effect of the environment on the features and especially on the polygenic features. The values of the coefficients of the estimated c broad sense heritability are shown in Table 4. If the range of heritability is divided into four categories: very low (less than 25%), low (between 25 and 52%), medium (between 52 and 55%) and more (more than 55%). The lowest inheritance value is assigned to fruit thickness (69%), which indicates that this property is not strongly influenced by environmental factors, after which the average inheritance associated with the characteristics of nut thickness was 69%. Thus, selection for this features in the breeding programs is associated with low efficiency. The inheritance of other measured characteristics was high. The most heritability belonged to oil content with inheritance was 100% (Table 4), indicating the very low impact of these characteristics from environmental factors. Basically, quantitative characteristics have variable heritability, as some of them have high heritability due to gene control by increased effect (Asma *et al.*, 2007). In some cases phenotypic variation is the result of hybridization (Azimi et al., 2018). Heritability values for these genotypes showed that, the genetic variance is more than the environmental variance, because in most of the characteristics high heritability values are estimated, so the first step in identifying local populations is to identify their morphological and phenological characteristics, because these characteristics are easily measurable and have a great practical application (Rotondi *et al.*, 2003). In this research, broad sense heritability of the features is also estimated. According to Stansfield's (1991) theory, if the inheritance of a feature is more than 50%, attribute have high heritability, if the broad sense heritability is between 20 and 50%, the inheritance property is moderate and if the broad sense heritability of the considered attribute is less from 20%, attribute has low inheritance. According to this theory, all characteristics were highly heritable and the average broad sense heritability for the studied characteristics was between 83% and 99%. Heredity for some attributes is low, and the reason is the largeness of their phenotypic variance, which is due to environmental influences. Some believe that if the inheritance of a trait is very high (more than 80%), selection will be relatively easy, because it is close to the genotype.

Conclusions

It was determined that the almond cultivars and hybrids were widely diverse in all pomological traits and oil content. For oil content trait, which is important for qualitative improvement in breeding programs, there was a significant difference between measured cultivars and hybrids. The most fruit and nut weight (31.3 and 3.5 gr) in13-23A and 13-51A hybrids respectively were observed. The lowest fruit and nut weight (4.3 and 0.5 gr) in 13-19A and 13-9A hybrids respectively. Also, the results showed that there was a genetic diversity among the studied cultivars and hybrids. The highest phenotypic and genotypic variance (13.05 and 11.18 respectively) were observed in fruit length. Also the highest broad sense heritability was related to nut weight (89%). The lowest phenotypic and genotypic variance coefficients of 0.19 and 0.15 genotype were kernel weight, respectively, and the lowest broad sense heritability was obtained in fruit thickness hybrid (68%). In this study, it was found that, the average oil percentage between the hybrids resulting from Mamaie × Marcona is intermediate. In other words, the average oil percentage between hybrids is 53%, but in the case of Mamaie and Marcona, 61% and 52% respectively. Also, some of the hybrids were high in oil, for example, the hybrid A11-18 had 63.97% of oil that could be used in almond development programs.

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