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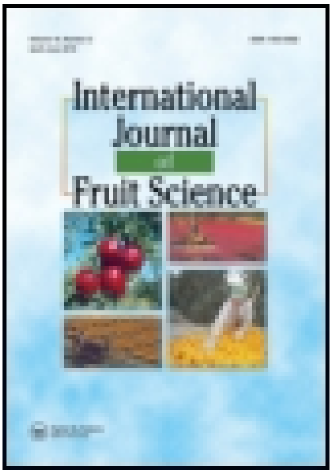

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Physical Fruit Traits in Moroccan Almond Seedlings: Quality Aspects and Post-Harvest Uses

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Physical Fruit Traits in Moroccan Almond Seedlings: Quality Aspects and Post-Harvest Uses

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The physical traits of local almond populations from Morocco were studied to characterize their genetic resources and to evaluate the possibility of their commercial valorization. Nut weight ranged between 1.15 and 7.39 g, and kernel weight between 0.54 and 1.85 g, but most accessions were characterized by small kernels, pronounced wrinkles, and double kernels. Although the physical quality of the kernels of these populations was low, they show the possibility of some specialized uses, which could improve their marketable value. The genotypes with favorable values could be incorporated into an almond breeding program as parents to increase the kernel quality.

KEYWORDS Prunus amygdalus *Batsch, almond, genetic diversity, breeding, kernel traits, nut traits, valorization, multivariate analysis*

INTRODUCTION

Almond is the most important nut tree cultivated in Morocco. The total almond acreage is about 146,100 ha and two important production systems can be differentiated: modern and traditional (Ministry of Agriculture, 2011). The modern system is characterized by the dominance of four cultivars: Marcona, Fournat de Brézenaud, Ferragnès, and Ferraduel (Kodad and Socias i Company, 2010; Lansari et al., 1994), with a density of 150 to 300 trees/ha

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(Loussert et al., 1989). Trees are mostly grafted on ‘Marcona’ seedlings and conducted according to modern techniques under favorable climatic conditions. Although most modern almond orchards are located in production areas where irrigation is possible, only a few are irrigated (Mahhou and Denis, 1992). The traditional system covers more than 70,000 ha and is found in inauspicious regions, mainly in mountainous and arid areas (Lansari et al., 1998). In this traditional system, almonds are grown under conditions where one or more environmental requirements are limiting. These include water during the growing season, soil depth, and nutrient availability, primarily N. Trees (mostly open-pollinated seedlings) are planted on slopes and hillsides, along streams, or interplanted with field crops, and are given little or no care (Mahhou and Denis, 1992), at an average density of 80 trees/ha, and are neither pruned nor sprayed. This system represents more than 80% of the almond surface in Morocco, with an estimated average production of 80 kg/ha (Ministry of Agriculture, 2011), harvested by the local farmers, used by the family, or sold locally (Lebrigui, 2011).

Despite their low productivity, seedling trees represent a potential source of germplasm, both for selecting new cultivars and for use as parents in breeding programs. Several studies have been conducted to evaluate the genetic diversity of the local almond seedlings in Morocco in order to select the best genotypes to be introduced in reference collections. The genetic structure of these populations has shown the presence of a great variability among genotypes of the same population (Lansari et al., 1994), but also among populations (Lansari et al., 1998). Selection of local almond genotypes for late-bloom, and frost and disease resistance have been carried out since 1975 (Barbeau and El Bouami, 1979; Laghezali, 1985). These studies have allowed the identification of genotypes of high yielding potential due to high spur density (Lansari et al., 1994), or with kernels of good physical quality (Lansari et al., 1994; Oukabli et al., 2007).

One of the most important objectives of the new strategy of the Ministry of Agriculture in Morocco is enhancing the almond production in the traditional sector in order to improve its marketing and to increase the income of the local growers (Ministry of Agriculture, 2011), taking into account the high level of poverty in these regions and the importance of almond in the economy of the households (Lebrigui, 2011). Almond commercial quality refers to all aspects related to the external appearance of the product, including size, shape, surface texture, kernel color, absence of double kernels, and, ultimately, the level of marketable kernels (Socias i Company et al., 2008). The first step to improve the commercialization of any horticultural product is its characterization and description. Thus, the main objective of the present work was the evaluation of the physical fruit quality traits in the main important local almond populations in Morocco for improving the characterization of the Moroccan genetic resources of almond and analyzing their possible impact on the commercial value of the crop.

MATERIALS AND METHODS

This study was carried out in five different regions with wealthy almond genetic resources: Aknoul and Al Hoceima situated in the Rif Mountains (north of Morocco), Azilal in the high Atlas Mountains (central Morocco), and the valleys of Sfasif and Tadla (central Morocco). A total of 41 local genotypes from different zones of each region were selected because of the general status of the plant (vigor, ramification, foliar density, and appearance), physical quality of kernel, late blooming, and appreciation of their kernel by the local population. These genotypes were marked and fruits were collected in the summer (7–10 Aug.) at maturity, when fruit mesocarp was fully dried and split along the fruit suture and peduncle abscission was complete. During two consecutive years (2009–10), a sample of 50 fruits was collected randomly around the canopy from the marked plants.

Nut thickness and width were measured at the midpoint of the length, perpendicular to each other, considering width the larger dimension. Length, width, and thickness were measured with a precision of 0.01 mm in all nuts with a digital caliper. After measurements, nuts were cracked to obtain the kernel and determine the shelling percentage by weight using an electronic balance. Length, width, and thickness were similarly measured in all kernels. These variables allowed the determination of the sphericity index (geometric diameter/length) of fruit and kernel, which is used to define their shape (Aydin, 2003). Kernel weight/nut weight is commonly used to describe shell hardness (Kester and Asay, 1975). The traits and their definition are summarized in Table 1.

All statistical analyses were performed with the SAS program (SAS, 2000). The principal component analysis (PCA) was applied to the average data of both years to describe the pattern of almond diversity. In PCA, intercorrelation among variables (component) was 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 maximal amount of variance in the data set and its direction are often explained by the first PC. Each PC is defined by a vector known as the eigenvector of the variance-covariance matrix. PCA is used to establish correlations between variables and to visualize the relationships of individuals in two- or three-dimensional graphs. The best model with the minimum number of dimensions explaining the data structure was selected by the exclusion rule, based on the amount of residual variability to be tolerated, retaining a sufficient number of PCs capable of explaining a percentage of variance >80%.

TABLE 1 Pomological Traits Analyzed in the Evaluation of the Physical Quality of Local Almond Moroccan Populations, Units, and Abbreviations

Trait	Unit	Abbreviation
Nut traits		
Nut weight	g	NW
Nut length	mm	NL
Nut width	mm	Nw
Nut thickness	mm	NT
Nut width/nut length		R1
Shell weight	g	SW
Nut sphericity	%	Øn
Nut geometric mean diameter (mm)	mm	ND
Kernel traits		
Kernel weight	g	KW
Kernel length	mm	KL
Kernel width	mm	Kw
Kernel thickness	mm	KT
Kernel length/kernel width		R2
Kernel sphericity	%	Øk
Kernel geometric mean diameter (mm)	mm	KD
Shelling percentage	%	SP

RESULTS AND DISCUSSION

Nut Quality

In-shell fruit weight varied between 1.15 and 7.39 g (Table 2). Fifteen genotypes had fruit weight lower than 3 g, 12 genotypes between 3 and 4 g, and 20 genotypes between 4 and 7 g. Thus, almost all selected genotypes present small in-shell fruit and, consequently, small kernel size because of their correlation (Kester et al., 1977; Kodad, 2006), as it happens with most local Moroccan genotypes (Barbeau and El Bouami, 1979; Laghezali, 1985; Lansari et al., 1994).

Shell traits are very important for kernel protection during manipulation and processing (Socias i Company et al., 2008). Almond shells are generally characterized by their hardness, shell-seal integrity, and shelling percentage. Shell hardness is inversely related to shelling percentage, and whereas it does not directly influence kernel quality, hard shells can reduce the proportion of nut meats recovered after shelling if adequate equipment is not utilized (Socias i Company et al., 2008). Shelling percentage in these genotypes ranged between 15.6% and 63.67% (Table 2), with 68% of the genotypes with very hard shell (10% to 30% of shelling percentage), 19% with hard shell (30% to 50%), and only 12% with soft shells (50% to 70%). Thus, almost all local almond selections produce hard to very hard shells, showing that with this kernel protection the nuts can be stored for a long time if not exposed to sunlight due to the fact that intact hard shells protect

TABLE 2 Mean Values of the Physical Nut and Kernel Traits Utilized in the Evaluation of the Physical Quality of Local Almond Moroccan Populations

Genotype	Region	NW^z	SW	NL	Nw	NT	R1	ND	Øn	KW	KL	Kw	KT	R2	KD	Øk	SP
AK1	Aknoul	4.96	3.76	33.90	22.66	17.08	0.67	22.85	67.41	1.20	22.84	13.74	7.65	0.60	13.05	57.11	24.17
AK10		2.75	2.16	25.04	18.02	13.22	0.72	17.62	70.37	0.59	17.81	10.53	6.55	0.59	10.46	58.72	21.28
AK11		3.32	2.63	19.25	23.56	17.06	1.22	19.20	99.72	0.69	17.57	11.30	8.79	0.64	11.74	66.83	20.77
AK12		2.65	2.03	24.11	20.73	14.02	0.86	18.58	77.06	0.62	16.82	11.40	6.50	0.68	10.51	62.48	23.47
AK13		3.37	2.43	19.77	23.96	16.77	1.21	19.37	97.95	0.94	23.19	12.65	6.49	0.55	12.08	52.11	27.79
AK14		4.79	3.83	29.89	23.67	16.56	0.79	22.02	73.65	0.95	21.15	13.77	7.04	0.65	12.39	58.56	19.91
AK2		4.19	3.11	36.72	24.00	14.14	0.65	22.46	61.19	1.09	25.08	13.44	7.34	0.54	13.18	52.56	25.92
AK3		5.01	3.86	34.54	23.32	17.20	0.68	23.27	67.36	1.16	24.75	14.01	7.40	0.57	13.34	53.89	23.05
AK4		7.34	6.19	40.58	24.91	17.09	0.61	25.02	61.66	1.15	26.95	12.64	7.39	0.47	13.25	49.16	15.66
AK5		6.99	5.53	37.75	26.87	19.61	0.71	26.21	69.45	1.46	24.68	15.15	7.53	0.61	13.75	55.71	20.94
AK6		3.76	3.19	22.44	24.22	16.39	1.08	20.11	89.62	0.57	17.09	11.72	6.39	0.69	10.60	62.03	15.05
AK7		4.56	3.54	32.87	22.47	14.99	0.68	21.60	65.73	1.02	23.59	12.91	7.00	0.55	12.55	53.19	22.27
AK8		3.51	2.62	31.20	18.97	13.47	0.61	19.39	62.15	0.88	22.43	12.00	6.70	0.53	11.87	52.93	25.21
AK9		3.40	2.62	31.62	21.66	12.53	0.69	19.86	62.83	0.78	20.00	13.06	5.57	0.65	11.06	55.27	22.86
AZ1	Azilal	3.05	2.23	28.59	21.96	13.91	0.77	19.98	69.89	0.81	20.84	12.51	6.91	0.60	11.87	56.93	26.70
AZ2		3.82	3.02	32.16	21.87	13.37	0.68	20.48	63.68	0.80	22.73	13.65	5.62	0.60	11.74	51.64	20.93
AZ3		4.61	3.65	35.62	22.76	15.82	0.64	22.68	63.67	0.96	25.69	13.35	5.99	0.52	12.39	48.25	20.78
AZ4		5.01	3.99	31.20	23.51	17.49	0.75	22.68	72.71	1.01	21.50	13.57	7.76	0.63	12.80	59.53	20.19
AZ5		4.61	3.69	31.95	23.59	15.40	0.74	21.94	68.69	0.93	20.14	13.52	6.52	0.67	11.81	58.62	20.10
AZ6		4.35	3.20	36.13	24.42	14.30	0.68	22.56	62.44	1.15	22.85	13.67	7.55	0.60	12.97	56.76	26.44
AZ7		4.29	3.34	29.49	21.54	16.19	0.73	21.09	71.50	0.95	21.81	12.92	7.18	0.59	12.33	56.54	22.06
AZ8		4.46	3.47	35.89	24.30	14.24	0.68	22.44	62.53	0.99	24.25	13.54	5.95	0.56	12.19	50.25	22.11
AZ9		3.37	2.64	29.19	20.81	13.12	0.71	19.39	66.41	0.73	23.94	12.04	5.49	0.50	11.37	47.50	21.74
BM1	Bni Mellal	4.76	3.78	34.19	23.02	15.30	0.67	22.21	64.97	0.99	24.14	13.30	6.91	0.55	12.71	52.65	20.68
BM2		1.93	1.36	22.77	17.30	11.48	0.76	16.08	70.63	0.57	17.71	10.60	6.41	0.60	10.39	58.66	29.68
BM3		1.91	1.37	20.38	18.13	12.05	0.89	16.00	78.49	0.54	15.02	11.23	6.34	0.75	9.99	66.50	28.42
BM4		2.26	1.64	25.88	17.79	12.05	0.69	17.20	66.47	0.61	18.27	10.78	6.52	0.59	10.61	58.10	27.21
BM5		3.52	2.73	26.18	24.37	14.67	0.93	20.44	78.07	0.79	18.60	13.12	6.73	0.71	11.51	61.86	22.38

(*Continued*)

TABLE 2 (Continued)

Genotype	Region	NW[z]	SW	NL	Nw	NT	R1	ND	Øn	KW	KL	Kw	KT	R2	KD	Øk	SP
H1	Al Hoceima	6.52	5.05	40.37	26.99	18.56	0.67	26.36	65.29	1.47	26.89	15.36	7.01	0.57	13.88	51.62	22.51
H10		2.31	1.11	29.27	19.83	15.15	0.68	20.03	68.43	1.20	22.90	13.78	8.53	0.60	13.55	59.15	51.78
H2		4.03	2.95	33.84	23.68	15.26	0.70	22.33	65.97	1.08	24.33	13.93	6.87	0.57	12.91	53.08	26.82
H3		3.35	1.66	41.24	25.42	14.74	0.62	24.12	58.48	1.69	27.41	16.39	7.78	0.60	14.77	53.88	50.34
H4		1.63	0.77	31.09	17.24	12.35	0.55	18.23	58.65	0.86	22.19	10.64	6.87	0.48	11.46	51.66	52.79
H5		4.94	3.69	37.61	23.89	16.90	0.64	23.98	63.76	1.25	27.62	14.05	6.81	0.51	13.46	48.75	25.25
H6		1.83	0.99	33.86	20.45	13.49	0.60	20.43	60.32	0.84	22.11	11.87	6.76	0.54	11.81	53.41	46.10
H7		3.79	2.64	35.95	22.12	17.16	0.62	23.15	64.39	1.15	24.36	12.79	7.82	0.53	13.11	53.83	30.47
H8		1.77	0.64	34.37	21.46	13.71	0.62	20.97	61.01	1.13	24.38	14.01	7.43	0.57	13.29	54.49	63.79
H9		2.46	1.17	33.82	23.23	14.60	0.69	21.86	64.63	1.29	23.18	14.25	7.21	0.61	13.01	56.13	52.38
Sf1	Sfasif	1.15	0.61	20.21	15.90	12.24	0.79	15.35	75.98	0.54	15.37	10.46	7.90	0.68	10.57	68.81	47.11
Sf2		2.00	1.07	29.38	20.42	14.91	0.70	20.14	68.55	0.93	21.88	12.71	7.61	0.58	12.51	57.19	46.34
Sf3		1.80	0.89	28.60	20.00	13.77	0.70	19.31	67.53	0.90	21.33	12.61	7.32	0.59	12.22	57.31	50.80
Sf4		2.15	1.22	26.15	20.52	15.51	0.78	19.66	75.20	0.93	19.23	13.28	8.73	0.69	12.73	66.20	43.11
Sf5		2.99	1.93	34.41	22.57	14.13	0.66	21.54	62.61	1.06	24.62	14.10	7.05	0.57	13.13	53.34	35.57
Sf6		3.62	2.47	30.97	22.26	15.06	0.72	21.15	68.29	1.15	24.29	13.29	7.70	0.55	13.20	54.35	31.80
Sf7		4.48	2.64	40.70	27.19	16.85	0.67	25.66	63.05	1.85	29.03	17.67	7.12	0.61	14.98	51.61	41.21

[z] Abbreviations are defined in Table 1.

kernels from both insect damage and deterioration from molds (Schirra, 1997; Thompson et al., 1996).

Pre-harvest and post-harvest damage is more common in soft shell cultivars because soft shells may provide an entry point for insects and fungi (Gradziel and Martínez-Gómez, 2002). Insect larvae, such as navel orange worm, *Amyelois transitella* (Rice et al., 1996), may cause early-season damage because it can more easily penetrate the developing soft shell, reducing kernel quality (Crane and Summers, 1971). This vulnerability is aggravated when almond nuts are harvested from the ground where they are readily contaminated, especially if the shell is not well sealed (Reil et al., 1996; Thompson et al., 1996).

The separation of shell fragments from shelled nuts is, however, more difficult with hard-shell cultivars because of the similarities in density between the kernel and shell fragments (Schirra, 1997). Consequently, distinct industries have developed based on the shell types in different growing regions. In the Mediterranean region, most cultivars are hard-shelled and the processing plants are designed for cracking these types (Socias i Company et al., 2008). Thus, the processing plants to be adopted by the Moroccan industries must be adapted to hard shells. Consequently, hard-shell and soft-shell almonds must be separated by the growers and the industry in order to avoid kernel breakage during the mechanical shelling and increasing the product value.

Nut shape also affects mechanical shelling because the sheller must be adjusted depending on nut size and shape. Almond nuts are frequently marketed in Morocco as a mixture of different sizes and shapes, increasing the percentage of broken kernels at shelling. Nut shape was determined according to the IPGRI guidelines (Gülcan, 1985) and by the sphericity index (Tables 2 and 3). Nuts were extremely narrow for 46% of the genotypes, ovate to round for 28%, and oblong for 27%.

Kernel Quality

The kernel is the edible part of the nut and is considered an important food crop, with a high nutritional value. It may be consumed raw or cooked, blanched or unblanched, combined and/or mixed with other nuts. It can also be transformed to be incorporated into other products or to produce marzipan and nougat (Schirra, 1997). Each one of the end uses of almond depends on different physical traits and the chemical composition of the kernel (Socias i Company et al., 2008; Berger, 1969). Kernel size is commercially important, as larger sizes generally confer greater value (Socias i Company et al., 2008), because size may imply kernel use (Cavaletto et al., 1985). Kernel size depends on kernel weight, ranging in the genotypes studied from 0.54 to 1.85 g (Table 2), being classified (Gülcan, 1985) as very

TABLE 3 Qualitative Nut and Kernel Traits Utilized in the Evaluation of the Physical Quality of Local Almond Moroccan Populations

Genotype	Blooming time^z	Nut shape	Shell hardness	Kernel shape	Tegument color	Shriveling of the kernel	Double kernels (%)	Tegument pubescence	Kernel taste
AK1	3	Medium	Very hard	Cordate	Dark	Wrinkled	48	High	Sweet
AK10	3	Very small	Very hard	Round	Dark	Wrinkled	56	High	Intermediate
AK11	4	Very small	Very hard	Round	Intermediate	Slightly wrinkled	60	Extremely high	Sweet
AK12	5	Very small	Very hard	Round	Dark	Slightly wrinkled	20	Extremely high	Sweet
AK13	4	Small	Hard	Cordate	Dark	Slightly wrinkled	16	Extremely high	Sweet
AK14	4	Small	Very hard	Cordate	Intermediate	Slightly wrinkled	8	High	Sweet
AK2	3	Small	Very hard	Cordate	Light	Intermediate	44	Intermediate	Intermediate
AK3	2	Medium	Very hard	Cordate	Intermediate	Slightly wrinkled	48	Intermediate	Intermediate
AK4	2	Medium	Very hard	Cordate large	Light	Slightly wrinkled	64	Low	Sweet
AK5	2	Large	Very hard	Cordate	Dark	Slightly wrinkled	48	Low	Sweet
AK6	3	Very small	Very hard	Round	Dark	Slightly wrinkled	56	Intermediate	Sweet
AK7	2	Small	Very hard	Cordate	Dark	Wrinkled	68	Low	Sweet
AK8	1	Very small	Very hard	Cordate	Dark	Wrinkled	52	Intermediate	Sweet
AK9	2	Very small	Very hard	Cordate	Dark	Intermediate	36	Intermediate	Sweet
AZ1	5	Very small	Very hard	Cordate	Dark	Wrinkled	44	Intermediate	Sweet
AZ2	4	Very small	Very hard	Oblong	Intermediate	Intermediate	32	Intermediate	Sweet
AZ3	5	Small	Very hard	Oblong	Dark	Intermediate	20	High	Sweet
AZ4	5	Small	Very hard	Round	Dark	Slightly wrinkled	48	High	Sweet
AZ5	5	Small	Very hard	Cordate	Intermediate	Slightly wrinkled	56	Intermediate	Sweet

AZ6	4	Medium	Very hard	Cordate	Intermediate	Slightly wrinkled	44	Low	Sweet
AZ7	3	Small	Very hard	Cordate	Dark	Slightly wrinkled	32	High	Sweet
AZ8	4	Small	Very hard	Oblong	Dark	Slightly wrinkled	20	Intermediate	Sweet
AZ9	4	Very small	Very hard	Oblong	Dark	Intermediate	40	Intermediate	Sweet
BM1	2	Small	Very hard	Cordate	Dark	Wrinkled	28	Extremely high	Intermediate
BM2	3	Very small	Hard	Round	Extremely dark	Wrinkled	44	Extremely high	Intermediate
BM3	1	Very small	Hard	Round	Extremely dark	Wrinkled	40	Extremely high	Sweet
BM4	3	Very small	Hard	Round	Dark	Intermediate	4	High	Sweet
BM5	3	Very small	Very hard	Round	Dark	Intermediate	44	High	Sweet
H1	2	Large	Very hard	Cordate large	Light	Wrinkled	44	High	Sweet
H10	1	Medium	Soft	Cordate	Dark	Slightly wrinkled	16	Extremely high	Sweet
H2	3	Small	Very hard	Cordate	Intermediate	Slightly wrinkled	32	Intermediate	Sweet
H3	3	Large	Soft	Cordate large	Intermediate	Wrinkled	24	Intermediate	Sweet
H4	4	Very small	Soft	Cordate	Light	Intermediate	44	Low	Sweet
H5	1	Medium	Very hard	Oblong	Dark	Wrinkled	20	High	Sweet
H6	2	Very small	Soft	Cordate	Intermediate	Slightly wrinkled	36	High	Intermediate
H7	3	Medium	Hard	Cordate	Dark	Slightly wrinkled	44	Intermediate	Intermediate
H8	4	Medium	Soft	Cordate	Intermediate	Intermediate	60	Intermediate	Sweet
H9	4	Medium	Soft	Cordate	Intermediate	Slightly wrinkled	72	Intermediate	Sweet

(*Continued*)

TABLE 3 (Continued)

Genotype	Blooming time^z	Nut shape	Shell hardness	Kernel shape	Tegument color	Shriveling of the kernel	Double kernels (%)	Tegument pubescence	Kernel taste
Sf1	3	Very small	Soft	Round	Dark	Wrinkled	40	Extremely high	Sweet
Sf2	3	Small	Soft	Cordate	Dark	Wrinkled	32	Extremely high	Sweet
Sf3	4	Very small	Soft	Cordate	Dark	Wrinkled	44	Extremely high	Intermediate
Sf4	4	Small	Soft	Round	Extremely dark	Wrinkled	48	High	Sweet
Sf5	4	Small	Soft	Cordate	Extremely dark	Wrinkled	28	High	Sweet
Sf6	4	Medium	Hard	Cordate	Dark	Intermediate	40	Extremely high	Sweet
Sf7	5	Large	Soft	Oblong	Dark	Intermediate	44	High	Sweet

^{z}1: Mid-December; 2: Last decade of December; 3: First week of January; 4: Last decade of January; 5: First week of February.

small in 37.8% (less than 0.9 g), small in 31% (0.9 to 1.1 g), medium in 22% (1.1 to 1.4 g), and large in 8% (1.4 to 1.8 g) (Table 2).

Almost all local almond populations produce small kernels. Not only may smaller kernels reduce yields for a given fruit load, but they are also less valued and paid. Dry matter accumulation in almond kernels takes place in late summer, when the evaporative demand is at its maximum and other growth processes are very much reduced (Kester et al., 1996). Kernel dry weight may be reduced by severe drought conditions (Goldhamer and Viveros, 2000) or even with moderate water stress during late summer (Girona et al., 2005). The small fruit of these selections may be explained by the fact that they are grown under arid conditions with long drought seasons. Medium to large kernels are desirable for most end uses, and small kernels are only appreciated for specialized uses, such as inclusion in chocolate bars, such as ‘Felisia’, with an average weight of 0.85 g (Socias i Company and Felipe, 1999) or ‘Milow’ of 0.82 g (Kester and Gradziel, 1996).

Kernel shape is a determinant trait for some specialized uses, as longer, more oblong kernels are often desirable for sliced or slivered products since these kernels produce a more uniform sliced product (Schirra, 1997). Kernel shapes are most easily distinguished by the extent and uniformity of length/width ratio (L/W) (Kester, 1965; Kester et al., 1980), without paying much attention to thickness (T) (Socias i Company et al., 2008). According to the almond descriptors (Gülcan, 1985), 4.4% of the genotypes produce narrow kernels (W/L from 0.43 to 0.49), 26.6% medium kernels (W/L from 0.50 to 0.56), 46.7% broad kernels (W/L from 0.57 to 0.63), and 22.2% very broad kernels (W/L $\geq$ 0.64). Kernel length, and to a lesser degree kernel width, is largely predetermined by the size of the seed cavity during early fruit development, whereas kernel thickness is more dependent on final seed fill, which is more vulnerable to late-season environmental stresses, such as drought and diseases (Kester and Gradziel, 1996). Thus, Valverde et al. (2006) reported that, under non-irrigated conditions, ‘Guara’ produced kernels of greater mass (M), length (L), and width (W), while under irrigation kernels were thicker and more spherical. Kernel thickness in these Moroccan genotypes ranged from 5.49 to 8.79 mm (Table 2). According to the almond descriptors (Gülcan, 1985), 11.1% of the genotypes had very thin kernels (<6 mm), 36.6% thin kernels (from 6 to 6.9 mm), 46.7% medium kernels (from 7 to 7.9 mm), and 7.7% thick kernels (from 8 to 8.9 mm). Thus, almost all Moroccan almond seedlings produce kernels from very thin to medium, probably due to late-season environmental stresses, such as drought and diseases).

About 35% of the genotypes produced kernels with pronounced wrinkle (Table 3). This trait is not desirable for direct consumption because consumers prefer smooth and uniform without pronounced wrinkle (Cavalleto et al., 1985). A high wrinkling degree is also reflected on the surface of blanched kernels, creating an undesirable appearance. Slight wrinkling, however, may be important in salted and flavored nuts because these kernels may hold more seasoning on their increased surface area (Cavalleto et al., 1985). In relation to the seed coat color and texture, 90% of these genotypes showed a tegument with intermediate to dark color and more than 90% a rough surface texture (Table 3). Seed coats of light color and smooth surface are preferred (Socias i Company et al., 2008). However, a rough "pubescence" also facilitates a more uniform coating of processed almond kernels with salts and other flavorings, but it may also confer a "papery" mouthfeel. A greater pubescence is associated with darker seed coat color and is less desirable for nuts consumed raw (Socias i Company et al., 2008). Thus, fruits of these genotypes could be consumed blanched or they must be isolated during the sorting process to be destined to other uses than to direct consumption.

Double kernels were produced by all of these genotypes with percentages ranging from 3% to 64% (Table 3). In some southeastern areas, almond populations showed higher percentages of double kernels, sometimes attaining 100%; this trait has been selected by local growers (Lansari et al., 1994) because the shell cavity is generally more filled by the kernels in these genotypes and the shelling percentage is higher. Double kernels occur when two seeds are present within the nut and result from the fertilization and development of both ovules normally present in the ovary. Several physiological and climatic causes have been suggested to favor this trait, but none has been clearly documented. Low temperatures before blooming (Egea and Burgos, 1994) or at blooming time (Rikhter, 1969; Spiegel-Roy and Kochba, 1974) have been mentioned as promoting higher percentages of double kernels. The earliest blooming flowers seem to be the ones that produce the largest number of double kernels (Socias i Company and Felipe, 1994). All of the studied genotypes are early blooming (Table 3), which could explain the high percentages of double kernels. This trait is considered to be negative, lowering crop value (Kester et al., 1980), since the simultaneous development of both kernels usually results in deformed nuts, which makes the processes of shelling, size selection, and blanching difficult (Socias i Company et al., 2008). Double kernels are misshapen and, therefore, unsuitable for use as salted nuts or for slicing. Although a small percentage can be tolerated, significant amounts are undesirable. Thus, to improve the commercial values of the local almond cultivars, the growers must harvest separately the genotypes with high percentages of double kernels.

Diversity Analysis

Statistical methods, such as principal component analysis and cluster analysis, are useful tools for studying the genetic diversity and have been applied to fruit species, such as almond (Lansari et al., 1994), olive (*Olea europea* L.)

TABLE 4 Eigenvectors of the Three Principal Component Axes from PCA Analysis of the Moroccan Almond Seedlings

Variables	Axe1	Axe2	Axe3
Nut weight (g)	0.06	0.45	0.07
Nut length (mm)	0.31	0.06	−0.20
Nut width (mm)	0.24	0.31	0.09
Nut thickness (mm)	0.25	0.21	0.36
Shell weight (g)	−0.01	0.46	0.05
Kernel weight (g)	0.31	−0.11	0.06
Kernel length (mm)	0.32	0.02	−0.07
Kernel width (mm)	0.31	−0.07	0.00
Kernel thickness (mm)	0.19	−0.29	0.44
Nut width/nut length	−0.29	0.11	0.31
Kernel length/kernel width	−0.30	−0.13	0.11
Nut sphericity (%)	−0.27	0.15	0.37
Kernel sphericity (%)	−0.28	−0.14	0.27
Shelling percent (%)	0.18	−0.38	0.01
Kernel geometric mean diameter (mm)	0.19	−0.29	0.42
Nut geometric mean diameter (mm)	0.25	0.22	0.33

(Cantini et al., 1999), and peach (Nikolić et al., 2010). The PCA, applying the mentioned exclusion rule, allowed explaining 87.38% of the sample variability with the first two PCs (Table 4). The contribution of each PC to the total variance is shown in Table 4. Kernel weight, length, width, sphericity index, length/width ratio, and in-shell fruit length were primarily responsible for the separation on the PC1. The second component is represented by in-shell weight and width, shell weight, and shelling percentage, and the third component is represented by nut and kernel thickness and geometric diameter, nut sphericity index, and length/width ratio.

When means were plotted on the two principal axes (Fig. 1), the almond population of Al Hoceima had a high positive value on PC1. This showed the highest values for kernel weight, length, and width, and the lowest values for sphericity index and length/width ratio (Tables 5 and 6). In contrast, the population of Bni Mellal had a high negative value on the first component (Fig. 1), indicating that this population showed the lowest values for kernel weight, length, and width, and the highest values for sphericity index and length/width ratio (Tables 5 and 6). On the second component, these populations had slightly negative values showing an intermediate to high value of shelling percentage and low values of in-shell fruit and shell weight and in-shell fruit width (Tables 5 and 6). On the third component, both populations had a slightly negative value showing intermediate to low values of the variables explaining this component (Table 4). The almond population of Azilal, the second most important local population after Al Hoceima, had positive values on PC1 and PC2, showing intermediate values for kernel weight, length, and width, and low values for sphericity index,

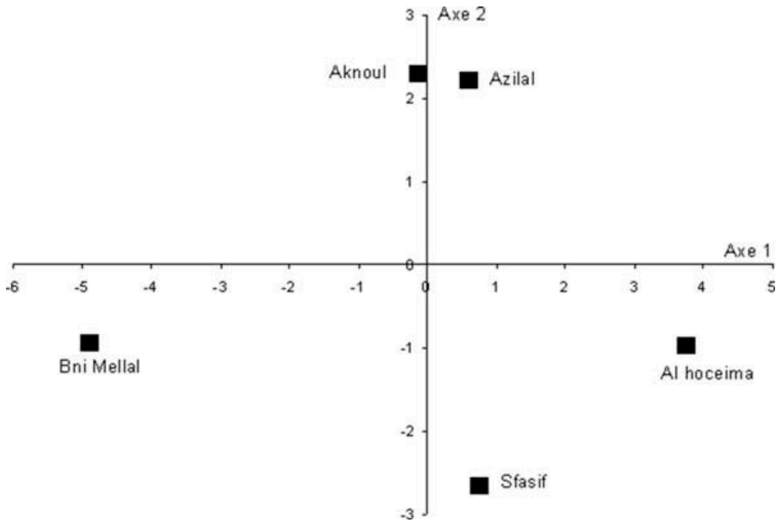

FIGURE 1 Position of the tow first principal components (PC) scores of the physical almond kernel of the five Moroccan almond populations.

TABLE 5 Mean Value of the Nut Traits of Each Local Population of Moroccan Almond Seedlings

Population	NW[z]	SW	NL	Nw	NT	ND
Aknoul	4.3 ± 1.37	3.4 ± 1.17	29.9 ± 6.56	22.7 ± 2.25	15.7 ± 1.94	2.5 ± 0.10
Azilal	4.2 ± 0.60	3.2 ± 0.52	32.2 ± 2.81	22.7 ± 1.21	14.8 ± 1.36	2.4 ± 0.07
Bni Mellal	2.8 ± 1.11	2.2 ± 0.95	25.8 ± 4.67	20.1 ± 2.96	13.1 ± 1.56	2.3 ± 0.09
Al-Hoceima	3.2 ± 1.59	2.1 ± 1.47	35.1 ± 3.77	22.4 ± 2.84	15.1 ± 1.88	2.4 ± 0.10
Sfasif	2.6 ± 1.16	1.5 ± 0.80	30.1 ± 6.43	21.2 ± 3.40	14.6 ± 1.45	2.4 ± 0.08

[z] Abbreviations are defined in Table 1.

length/width ratio, and shelling percentage, and high values of in-shell fruit weight and width and shell weight (Tables 5 and 6). On PC3, these populations showed a thin nut and kernel and medium to narrow nut (Table 4). The Sfasif population had slightly positive values on PC1 and PC2 (Fig. 1), characterized by intermediate values of the variables explaining this component (Table 4); however, on PC2, they showed the highest value of shelling percentage and the lowest values of the in-shell and shell weight (Tables 5 and 6). The almond population of Aknoul is characterized by intermediate to low values of the variables explaining the first component, and very low values of shelling percentage and very high values of in-shell fruit and shell weight on the PC2. This population showed thicker nuts and kernels and broad nuts (Table 4).

These results showed that the nuts produced in Aknoul and Azilal are the heaviest, 4.33 and 4.17 g, respectively, and those produced in Al Hoceima are the largest at 35 mm (Tables 5 and 6). The kernels produced in Al

TABLE 6 Mean Values of the Kernel Traits of Each Local Population of Moroccan Almond Seedlings

Population	KW^z	KL	Kw	KT	KD	SP
Aknoul	0.93 ± 0.26	21.7 ± 3.22	12.7 ± 1.21	7.1 ± 0.73	1.9 ± 0.07	22.1 ± 3.4
Azilal	0.92 ± 0.12	22.6 ± 1.67	13.2 ± 0.55	6.5 ± 0.79	1.8 ± 0.08	22.3 ± 2.3
Bni Mellal	0.70 ± 0.17	18.7 ± 2.98	11.8 ± 1.17	6.5 ± 0.21	1.8 ± 0.02	25.6 ± 3.5
Al-Hoceima	1.20 ± 0.25	24.5 ± 2.09	13.7 ± 1.63	7.3 ± 0.58	1.9 ± 0.05	42.2 ± 14.5
Sfasif	1.05 ± 0.40	22.6 ± 4.34	13.4 ± 2.18	7.6 ± 0.57	1.9 ± 0.05	42.2 ± 6.7

^{z}Abbreviations are defined in Table 1.

Hoceima and Sfasif are the heaviest (1.20 and 1.05 g, respectively) and largest (24.25 and 22.65 mm, respectively) than those produced in the other regions (Table 5 and 6). Furthermore, the shell of the populations of Al Hoceima and Sfasif is less hardy than that of the other populations (Table 5 and 6).

Our analysis allowed defining the genetic structure of the almond seedling populations in Morocco using the physical nut and kernel parameters in order to evaluate the regions with interesting populations. The objective was the identification and selection of the best genotypes to be incorporated as parents into almond breeding programs in Morocco in order to select new cultivars with good agronomical traits, medium blooming date, self-compatibility, and tolerance to drought stress.

CONCLUSION

The study was focused on evaluating the physical nut and kernel traits of the Moroccan almond seedlings from a qualitative point of view in order to better define the possible end uses of their production and the best machinery required to process the crop industrially. Results show that the kernels produced by the local almond seedling are of low quality, because of low kernel weight, seed coat darkness, high percentage of double kernels, and wrinkled kernels. These negative traits reduce the marketable value of this production because they do not meet the standards of physical quality required by the market (Schirra, 1997; Socias i Company et al., 2008). However, the chemical composition of these kernels reached a very high quality (Kodad et al., 2011, 2013), suggesting other potential post-harvest utilizations, such as the production of marzipan, almond floor, and oil. These industrial products could increase the marketable value of these local populations, thus increasing the income of the producers. The differences among the different Moroccan almond populations suggest the possibility of choosing the best regions for each product and the identification of the best genotypes for their possible incorporation as parents in almond breeding programs.

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