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PHYSICAL FRUIT TRAITS IN MOROCCAN ALMOND SEEDLINGS: QUALITY ASPECTS AND POST-HARVEST USES

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 could be differentiated: modern and traditional (Anonymous, 2011). The modern system is characterized by the dominance of four cultivars, 'Marcona', 'Fournat de Brézenaud', 'Ferragnès' and 'Ferraduel' (Lansari *et al.*, 1994), with a density of 150 to 300 trees/ha (Loussert *et al.*, 1989). Trees are mostly grafted on 'Marcona' seedlings and conducted according to modern techniques under favourable 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 mountain regions 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 (Anonymous, 2011), harvested by the local farmers, used by the family or sold locally.

Despite their low productivity, seedling trees represent a potential source of germplasm, both for selecting new cultivars and for use as parents in breeding programmes. 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 between genotypes of the same population (Lansari *et al.*, 1994), but also between populations (Lansari *et al.*, 1998). Selection of local almond genotypes for late-bloom, and frost and disease resistance have been carried out since 1975 (Laghezali, 1985). These studies have allowed the identification of genotypes of high yielding potential due to high spur density, or with kernels of good physical quality (Lansari *et al.*, 1994).

One of the most important objectives of the new strategy of the Ministry of Agriculture in Morocco is enhancing almond production in the traditional sector in order to improve its marketing and to increase the income of local growers (Anonymous, 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 colour, 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 and its possible impact on the commercial value of the crop.

MATERIAL AND METHODS

Plant material and fruit traits. This study was carried out in five different regions rich in 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 Saïs 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 (vigour, 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 summer (7-10 August) at maturity, when the fruit mesocarp was fully dried and split along the fruit suture and peduncle abscission was complete. During two consecutive years (2009-2010), 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 for 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.

Statistical Analysis. All statistical analyses were performed with the SAS program (SAS, 2000). A Principal Component Analysis (PCA) was applied to describe the pattern of almond diversity. In PCA, intercorrelation among variables (component) was removed, 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 dataset 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.

Table 1. Pomological traits analysed, units and abbreviations.

Trait	Unit	Abbreviation
Nut traits		
Nut weight	g	*PA*
Nut length	mm	*LA*
Nut width	mm	*LRA*
Nut thickness	mm	*EPA*
Nut width/nut length		*R1*
Shell weight	g	*Pq*
Nut sphericity	%	*Øn*
Nut geometric mean diameter (mm)	mm	*DpN*
Kernel traits		
Kernel weight	g	*PN*
Kernel length	mm	*LN*
Kernel width	mm	*LRN*
Kernel thickness	mm	*EPN*
Kernel length/kernel width		*R2*
Kernel sphericity	%	*Øk*
Kernel geometric mean diameter (mm)	mm	*Dpk*
Shelling percentage	%	Rdt

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 grams, 12 genotypes between 3 and 4 grams, and 20 genotypes between 4 and 7 g (Table 2). Thus, almost all selected genotypes present small in-shell fruit and, consequently, small kernel size because of their correlation (Kester *et al.*, 1977), as it happens with most local Moroccan genotypes (Lansari *et al.*, 1994).

Shell traits are very important for kernel protection during manipulation and processing. 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 because those intact hard shells protect kernels from both insect damage and deterioration from molds (Schirra, 1997).

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 can penetrate more easily the developing soft shell, reducing kernel quality (Crane and Summers, 1971). 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

Table 2. Mean values of the physical nut and kernel trait of each genotype.

Genotype	Region	PA	Pq	LA	LRA	EPA	R1	DpN	Øn	PN	LN	LrN	EPSN	R2	Dpk	Øk	Rdt
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	Bnimellal	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
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

Abbreviations are defined in Table 1.

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 increase the product value. Nut shape also affects mechanical shelling because the sheller must be adjusted to 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 and by the sphericity index (Tables 2, 3). Nuts were 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.

Table 3. Qualitative nut and kernel traits of each genotype.

Genotype	Nut shape	Shell hardness	Kernel shape colour	Tegument the kernel	Shrivelling of (%)	Double kernel pubescence	Tegument taste	Kernel
AK1	Medium	Very hard	Cordate	Dark	Wrinkled	48	High	Sweet
AK10	Very small	Very hard	Round	Dark	Wrinkled	56	High	Intermediate
AK11	Very small	Very hard	Round	Intermediate	Slightly wrinkled	60	Extremely high	Sweet
AK12	Very small	Very hard	Round	Dark	Slightly wrinkled	20	Extremely high	Sweet
AK13	Small	Hard	Cordate	Dark	Slightly wrinkled	16	Extremely high	Sweet
AK14	Small	Very hard	Cordate	Intermediate	Slightly wrinkled	8	High	Sweet
AK2	Small	Very hard	Cordate	Light	Intermediate	44	Intermediate	Intermediate
AK3	Medium	Very hard	Cordate	Intermediate	Slightly wrinkled	48	Intermediate	Intermediate
AK4	Medium	Very hard	Cordate large	Light	Slightly wrinkled	64	Low	Sweet
AK5	Large	Very hard	Cordate	Dark	Slightly wrinkled	48	Low	Sweet
AK6	Very small	Very hard	Round	Dark	Slightly wrinkled	56	Intermediate	Sweet
AK7	Small	Very hard	Cordate	Dark	Wrinkled	68	Low	Sweet
AK8	Very small	Very hard	Cordate	Dark	Wrinkled	52	Intermediate	Sweet
AK9	Very small	Very hard	Cordate	Dark	Intermediate	36	Intermediate	Sweet
AZ1	Very small	Very hard	Cordate	Dark	Wrinkled	44	Intermediate	Sweet
AZ2	Very small	Very hard	Oblong	Intermediate	Intermediate	32	Intermediate	Sweet
AZ3	Small	Very hard	Oblong	Dark	Intermediate	20	High	Sweet
AZ4	Small	Very hard	Round	Dark	Slightly wrinkled	48	High	Sweet
AZ5	Small	Very hard	Cordate	Intermediate	Slightly wrinkled	56	Intermediate	Sweet
AZ6	Medium	Very hard	Cordate	Intermediate	Slightly wrinkled	44	Low	Sweet
AZ7	Small	Very hard	Cordate	Dark	Slightly wrinkled	32	High	Sweet
AZ8	Small	Very hard	Oblong	Dark	Slightly wrinkled	20	Intermediate	Sweet
AZ9	Very small	Very hard	Oblong	Dark	Intermediate	40	Intermediate	Sweet
BM1	Small	Very hard	Cordate	Dark	Wrinkled	28	Extremely high	Intermediate
BM2	Very small	Hard	Round	Extremly dark	Wrinkled	44	Extremely high	Intermediate
BM3	Very small	Hard	Round	Extremly dark	Wrinkled	40	Extremely high	Sweet
BM4	Very small	Hard	Round	Dark	Intermediate	4	High	Sweet
BM5	Very small	Very hard	Round	Dark	Intermediate	44	High	Sweet
H1	Large	Very hard	Cordate large	Light	Wrinkled	44	High	Sweet
H10	Medium	Soft	Cordate	Dark	Slightly wrinkled	16	Extremely high	Sweet
H2	Small	Very hard	Cordate	Intermediate	Slightly wrinkled	32	Intermediate	Sweet
H3	Large	Soft	Cordate large	Intermediate	Wrinkled	24	Intermediate	Sweet
H4	Very small	Soft	Cordate	Light	Intermediate	44	Low	Sweet
H5	Medium	Very hard	Oblong	Dark	Wrinkled	20	High	Sweet
H6	Very small	Soft	Cordate	Intermediate	Slightly wrinkled	36	High	Intermediate
H7	Medium	Hard	Cordate	Dark	Slightly wrinkled	44	Intermediate	Intermediate
H8	Medium	Soft	Cordate	Intermediate	Intermediate	60	Intermediate	Sweet
H9	Medium	Soft	Cordate	Intermediate	Slightly wrinkled	72	Intermediate	Sweet
Sf1	Very small	Soft	Round	Dark	Wrinkled	40	Extremely high	Sweet
Sf2	Small	Soft	Cordate	Dark	Wrinkled	32	Extremely high	Sweet
Sf3	Very small	Soft	Cordate	Dark	Wrinkled	44	Extremely high	Intermediate
Sf4	Small	Soft	Round	Extremly dark	Wrinkled	48	High	Sweet
Sf5	Small	Soft	Cordate	Extremly dark	Wrinkled	28	High	Sweet
Sf6	Medium	Hard	Cordate	Dark	Intermediate	40	Extremely high	Sweet
Sf7	Large	Soft	Oblong	Dark	Intermediate	44	High	Sweet

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 the different physical traits and the chemical composition of the kernel (Socias i Company *et al*., 2008). 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 small in 37.8% (less than 0.9 g), small in 31% (0.9 to 1.1 grams), medium in 22% (1.1 to 1.4 grams), and large in 8% (1.4 to 1.8 grams). Almost all local almond populations produce small kernels. Not only smaller kernels may reduce yields for a given fruit load, but 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 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 and drought conditions. 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 determining 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 *et al.*, 1980), without paying much attention to thickness (T) (Socias i Company *et al.*, 2008). According to 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 ≥ 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), whilst under irrigation kernels were thicker and more spherical. Kernel thickness in these genotypes ranged from 5.49 to 8.79 mm (Table 2). According to almond descriptors (Gülcan, 1985), 11.1% of the genotypes had very thin kernels (< 6mm), 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 kernels 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 flavoured nuts because these kernels may hold more seasoning on their increased surface area (Cavalleto *et al.*, 1985). In relation to the seed coat colour 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" facilitates a more uniform coating of processed almond kernels with salts and other flavorings, but it also may confer a "papery" mouth-feel. A greater pubescence is associated with darker seed coat colour 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 these genotypes with percentages ranging from 3% to 64% (Table 3). In some SE areas, almond populations showed higher percentages of double kernels, sometimes attaining 100%, because this trait has been selected by local growers (Lansari *et al.*, 1994). 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 favour this trait, but none has been clearly documented. Low temperatures before blooming (Egea and Burgos, 1994) or at blooming time (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 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 the genotypes with high percentages of double kernels separately.

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) and peach (Nikolić *et al.*, 2010). Consequently, PC analysis was applied to the average data of both years (Table 2). 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%. With this rule, the first two PCs were enough because they described 87.38% of the sample variability. 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, 6). In contrast, the population of Bnimellal had a high negative value on the first component (Fig. 1),

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

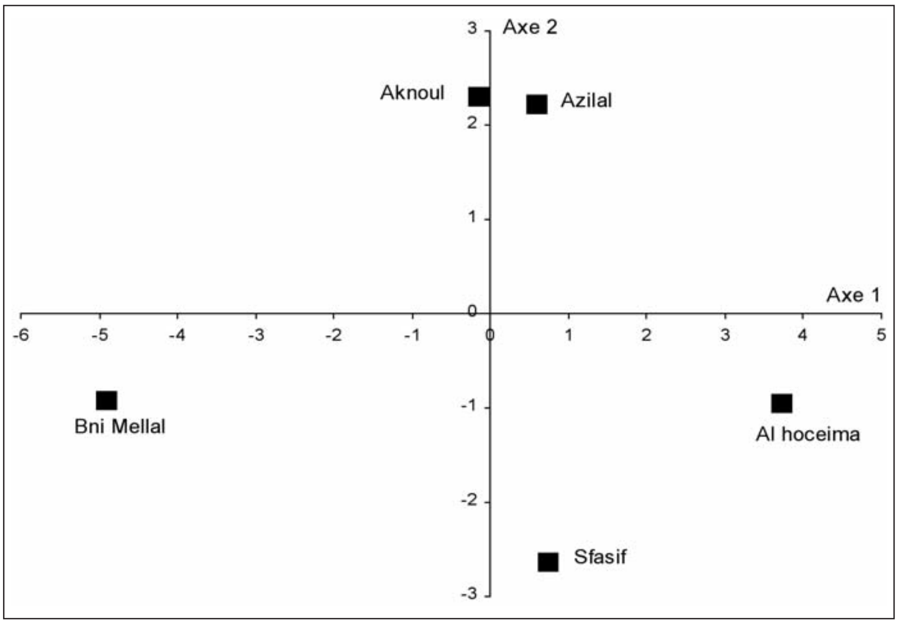


Table 4. Eigenvectors of the 3 principal components axes from PCA analysis of the Moroccan almond seedlings.

Variable	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 percentage (%)	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

Table 5. Means of nut traits of each population.

Region	PA	Pq	LA	LRA	EPA	DpN
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
BniMellal	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

Abbreviations are defined in Table 1.

Table 6. Means of kernel traits of each population.

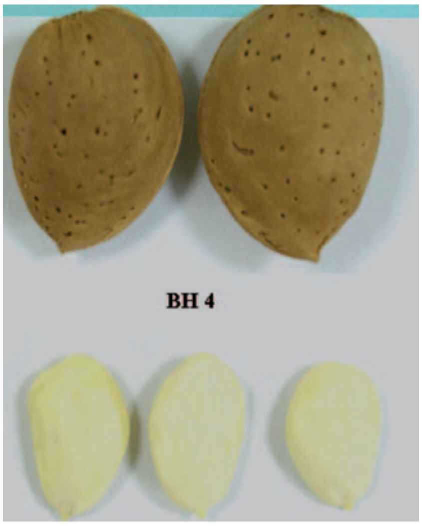
Region	PN	LN	LRN	EPSN	Dpk	Rdt
Aknoul	0.93±0.26	21.7±3.22	12.7±1.21	7.1±0.73	1.9±0.07	22.1±3.4
Azilal	0.92±0.12	22.6±1.67	13.2±0.55	6.5±0.79	1.8±0.08	22.3±2.3
BniMellal	0.70±0.17	18.7±2.98	11.8±1.17	6.5±0.21	1.8±0.02	25.6±3.5
Al-Hoceima	1.20±0.25	24.5±2.09	13.7±1.63	7.3±0.58	1.9±0.05	42.2±14.5
Sfasif	1.05±0.40	22.6±4.34	13.4±2.18	7.6±0.57	1.9±0.05	42.2±6.7

Abbreviations are defined in Table 1.

Insect damages on almond kernels. North of Morocco.

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 5,6). 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 5,6). 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 a positive value on PC1 and PC2, showing intermediate values for kernel weight, length and width, and low values for sphericity index, 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. 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 showed the highest value of shelling percentage and the lowest values of the in-shell and shell weight (Tables 5, 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. On the third axe 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, of 4.33 and 4.17 grams, respectively, and those produced in Al Hoceima the largest, 35 mm (Tables 5 and 6). The kernels produced in Al Hoceima and Sfasif are the heaviest (1.20 and 1.05 grams, respectively) and largest (24.25 and 22.65 mm, respectively) than those produced in the other regions (Table 5, 6). Furthermore, the shell of the populations of Al Hoceima and Sfasif is less hardy than that of the other populations (Table 5, 6).

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



Nut and kernel of selected almond tree.
North of Morocco.

CONCLUSION

The present study focused on evaluating 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 the resulting kernels and the best machinery required to process the crop industrially. The present results show that the kernels produced by local almond seedlings are of low quality, because of their 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 physical quality standards required by the market (Socias i Company *et al.*, 2008). However, the chemical composition of these kernels was of very high quality (Kodad *et al.*, 2011), suggesting others post-harvest utilizations, such as marzipan, almond flour and oil. These industrial products could increase the marketable value of these local populations, thus increasing producers' income. The differences between the various Moroccan almond populations suggest the possibility of selecting the best regions for each product and the identification of the best genotypes for their possible incorporation as parents in almond breeding programmes.

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