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Seed yield components, oil content, and fatty acid composition of two cultivars of moringa (*Moringa oleifera* Lam.) growing in the Arid Chaco of Argentina

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ABSTRACT

Moringa oleifera Lam. (*M. pterygosperma* Gaertn [Moringaceae]) is a fast-growing small tree native to the sub-Himalayan tracts of Northern India. The recognition that moringa oil has value in cosmetics has increased interest in cultivating it for seed-oil. The experimental trials were conducted in a semi-commercial moringa plantation in the subtropical northwestern region of Argentina, considering the similar climate conditions to the plant native region. Pods per tree, seeds per pod, weight of seed per pod, kernel weight, kernels oil content and fatty acid composition of PKM-1 and African cultivars were determined. One individual, E_4-9, a PKM-1 plant, had significantly ($P < 0.05$) higher production than all other plants. In addition, this individual was the highest extrapolated oil producer in both 2003 and 2004, with 595 and 564 kg ha^{-1}, respectively (ave. 580 kg ha^{-1}). Seed weight (200-seed wt.) was significantly greater in 2003 than 2004; no other traits studied showed significant differences between years. Both cultivars produced-oil with practically identical fatty acid composition, and the monounsaturated ω-9 oleic fatty acid accounted for more than 70% of the total for both cultivars. The polyunsaturated ω-6 linoleic fatty acid content of the African cultivar was slightly, but significantly ($P < 0.05$), higher than that of PKM-1.

1. Introduction

Moringa oleifera Lam. (*M. pterygosperma* Gaertn [Moringaceae]) is a fast-growing small tree native to the sub-Himalayan tracts of Northern India, which has been spread worldwide in tropical and subtropical countries (Rajangam et al., 2001). It has been grown in India since ancient times for a number of uses, including human foods, animal feed, and medicines (Acosta, 1578). However, this tree is valued mainly for the tender pods, which are esteemed as a vegetable. India remains the largest producer of moringa with a total of 42,613 ha, 90% located in the southern states of Tamil Nadu, Karnataka, Kerala and Andhra Pradesh (Rajangam et al., 2001).

Moringa seed contains 35–45% oil which is considered a great natural cosmetic emollient based on its tactile properties, almost total natural absence of color and odor, and high oleic acid concentration (>73%). The low content of polyunsaturated fatty acids (<1%) gives to the oil remarkable oxidative stability (Lalas and Tsaknis, 2002; Kleiman et al., 2008). Oxidative stability of moringa oil is higher than in other oils rich in oleic acid, such as high-oleic sunflower, meadowfoam, macadamia, hybrid safflower, safflower, almond and apricot oils (Kleiman et al., 2006).

The recognition that moringa oil has value in cosmetics has increased interest in cultivating it for seed-oil (Foidl et al., 2001). Tests of two cultivars, one from India and one from Africa were initiated to determine its potential in the Arid Chaco. Based on climate records it is likely that moringa could be adapted to this region.

2. Materials and methods

2.1. Study site and plant material

The experimental trials were conducted in a semi-commercial moringa plantation in the subtropical northwestern region of Argentina. The plantation is located at Fincas de Ambato farm, at an altitude of 525 m asl, and at 28° 28′ S. and 65° 46′ W. This is located in the Arid Chaco ecosystem, belonging to the province of Catamarca. Average rainfall from 1962 to 2006 was 394 mm per year, while temperatures ranged from −7.4 °C to 45.7 °C. The average number of days with frost is 7.9 (ranged from 0 to 14). Weather patterns of each growing season of the trial site are on Table 1. Soils of the region are typically rich in calcium and phosphorus, lacking in organic matter and nitrogen, and the average pH is 7.7 (Ayerza and Cook, 1996).

Two cultivars of moringa were used in this study: Periyakalum-1 (PKM-1) which has been selected in India for start production during the first year, and their high yield, and an African

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Table 1
Growing seasons' characteristics.

Period	Frost					Rain	Growing season
	First		Last		Total	October–April	Length
	day/mo	T °C	day/mo	T °C	days	mm	days
2002	–	–	4/8	−1.2	7	–	–
2003	10/7	−1	24/8	−2.1	6	–	–
2004	12/6	−2.5	–	–	–	–	–
2002–2003	–	–	–	–	–	304	340
2003–2004	–	–	–	–	–	219	290

accession from Tanzania of unknown selection pressure, but which will be referred to as the African cultivar in this paper.

Moringa seeds were sowing in the orchard by seed in 2001, spaced 1.2 m within the row, and 5 m between rows (1666 plants ha^{-1}), and were irrigated by a drip system. Each plantation was irrigated once a week starting on September and ending on April first both years. No fertilizer or pesticides were applied. PKM-1 was established in one plantation (E_4). Commercial seed obtained from East Africa (Tanzania) was used to establish a second plantation (E_5). A third plantation (D_5) was established using open-pollinated seed produced from the initial plantation of PKM-1. Growth and production of 510 plants which included plants from each row of each plantation were monitored since 2001. These 510 plants were not selected at random, but were selected for their comparatively faster plant establishment, branching, and flowering. Sowing dates and harvest dates for the three plantations are shown in Table 2.

For this study, a variable number of trees from each plantation were selected at random (total of 35 trees) from among the 510 trees which had been previously monitored. Data collected in 2003 and 2004 were used in this paper. Table 2 shows the number of selected trees per plantation. At the end of the harvesting season, trees' trunk diameters at a point approximately 50 mm above the soil line were measured using calipers.

2.2. Data collected

Mature pods were harvested from each tree by hand. They were dried in the shade, and then opened and cleaned by hand. Pods per tree, seeds per pod, weight of seed per pod, and per 200 seeds were determined for the 35 trees. Fifty-seed samples were selected at random from the total seeds produced by each tree in each of the three plantations, for seed weight determination. Seeds of four plants of each plantation were selected at random, seeds were dehulled and the kernel-weight determined. Kernels of these four plants were analyzed to determine oil content as a percentage of total kernel weight and fatty acid composition. All oil analyses were performed at the laboratory of International Flora Technologies Inc. (Chandler, Arizona, USA). The oil content percentage and fatty acid composition were determined by AOCS Ce 1e-91 using a Hewlett-Packard 5890 gas chromatography, with a flame ionization detector at 350 °C. The capillary column used was a 30 mm × 0.25 mm ID BPX with 0.25 micron film thicknesses (Palo Alto, USA), run isothermally at 340 °C.

2.3. Statistical analysis

To carry out the test, a randomized complete experimental design was used. To determine differences between years within a PKM-1 cultivar, and differences in oil content percentage and fatty acid composition between PKM-1 and the African cultivar, the data were subjected to analysis of variance and when the F-value was significant, the means were separated using Least Significant Test ($P < 0.05$) (Cohort, 2006).

3. Results

3.1. Seed and oil yield components. Results within a population

Yield components for nine individual plants of PKM-1 for two years are given in Table 3. Over the two years, tree E_4-9 had significantly ($P < 0.05$) higher yield of pods per tree than all other trees except E_4-5 and E_4-8. Average weight of seed per tree for tree E_4-9 over the two years was significantly greater ($P < 0.05$) than average weight of seed per tree for all other individuals. Tree E_4-1 had the highest number of seed per pod, however, it was significantly ($P < 0.05$) different than only two other trees, E_4-5 and E_4-7. The weight of 200 seeds was not significantly ($P < 0.05$) different between means of trees, but between E_4-4 and E_4-5 trees, having the last one significantly ($P < 0.05$) lower weight per 200 seed than the first one. Trees E_4-1 and E_4-6 had the highest weight of 50 kernels, and they were significant ($P < 0.05$) different from the yields of E_4-5, E_4-8, and E_4-2 trees. Kernels' oil percentage was high in that produced by E_4-9 and E_4-6 trees, but yields were not significant ($P < 0.05$) different from that produced by E_4-1, E_4-3, E_4-4, and E_4-5 trees. When productive characteristics were combined and results extrapolated to oil per tree and oil per ha, variability differences between trees were dramatically reduced, and just one tree, E_4-9, showed significantly ($P < 0.05$) higher production than all other individuals. In addition, this tree was the highest oil producer in both years with yields in 2003 and 2004 of 595 and 564 kg ha^{-1}, respectively (ave. 580 kg ha^{-1}).

Table 2
Catamarca moringa experimental plots' data.

Genotype	Origin	Plantation	Tree count	Sown date	Pods collection seasons		
			no.	dd/mo/yr	Plants age	Period	
					months	months	year
PKM-1	India	E_4	9	11/11/01	13–21	February–July	2003
PKM-1	India	E_4	9	11/11/01	24–32	March–June	2004
PKM-1	Argentina	D_5	13	12/09/03	6–10	March–June	2004
Africa	Tanzania	E_5	13	12/09/03	6–10	March–June	2004

Table 3
Differences on yields and yield components, within a population of moringa PKM-1, between years.

Tree	Trunk	Pods	Seeds			Kernel		Oil	
	Diameter	Tree	Yields	Quantity	Weight	Weight	Oil	Yields	
	cm	Quantity	g per tree	Per pod	g per 200 seeds	g per 50 kernels	(%)	g per tree	kg per ha
Year 2003									
E_4-1	35	86	426	18.4	53.8	37.8	37.30	120	200
E_4-2	35	104	464	16.7	53.5	35.0	31.89	104	173
E_4-3	36	196	930	15.9	59.8	37.6	38.64	270	450
E_4-4	35	137	784	13.7	83.6	35.5	39.11	218	363
E_4-5	24	144	374	12.9	40.3	36.4	37.60	102	170
E_4-6	30	77	392	16.2	63.0	37.9	40.83	121	202
E_4-7	26	40	121	15.3	59.0	36.9	36.00	32	54
E_4-8	31	102	487	17.9	53.4	36.4	35.76	127	211
E_4-9	43	352	1201	10.6	64.2	37.2	40.00	357	595
Average	32.8	137.6	575.4	15.3	59.0	36.7	37.5	161.2	268.7
S.D.[1]	5.74	91.98	332.44	2.49	11.66	1.02	2.69	100.93	168.15
Year 2004									
E_4-1	n/a	125	750	24.0	50.0	37.5	35.96	202	337
E_4-2	n/a	108	550	19.4	52.5	33.2	35.92	131	219
E_4-3	n/a	41	200	17.7	55.1	36.5	38.39	57	93
E_4-4	n/a	68	350	19.7	52.4	37.3	37.53	98	163
E_4-5	n/a	248	750	12.6	48.1	32.6	35.65	174	290
E_4-6	n/a	135	400	12.6	47.2	37.2	37.32	111	185
E_4-7	n/a	140	400	11.3	50.5	36.5	33.90	99	165
E_4-8	n/a	248	750	12.1	50.0	37.7	33.38	189	314
E_4-9	n/a	280	1200	18.0	47.6	36.6	38.56	339	564
Average		154.8	594.4	16.4	50.4	36.1	36.3	155.6	258.9
S.D.[1]		75.20	213.70	4.66	2.55	2.00	1.74	83.79	139.60
Mean									
E_4-1	25[1]	105.5^{b2}	587.9^{b}	21.2^{a}	51.9^{ab}	37.65^{a}	36.63^{abc}	161^{b}	269^{b}
E_4-2	35	106.0^{b}	507.2^{b}	18.1^{ab}	53.0^{ab}	34.1^{c}	33.91^{c}	117^{b}	196^{b}
E_4-3	36	118.5^{b}	565.1^{b}	16.8^{ab}	57.4^{ab}	37.05^{ab}	38.52^{ab}	163^{b}	272^{b}
E_4-4	35	102.5^{b}	567.1^{b}	16.7^{ab}	68.0^{a}	36.4^{abc}	38.32^{ab}	158^{b}	263^{b}
E_4-5	24	196.0^{ab}	561.9^{b}	12.7^{b}	44.2^{b}	34.5^{bc}	36.63^{abc}	158^{b}	230^{b}
E_4-6	30	106.0^{b}	395.9^{b}	14.3^{ab}	55.1^{ab}	37.55^{a}	39.06^{a}	116^{b}	194^{b}
E_4-7	26	90.0^{b}	260.5^{b}	11.3^{b}	50.5^{ab}	36.5^{abc}	34.95^{bc}	99^{b}	109^{a}
E_4-8	31	175.0^{ab}	618.6^{b}	14.9^{ab}	51.7^{ab}	37.05^{ab}	34.57^{bc}	158^{b}	263^{b}
E_4-9	43	316.0^{a}	$1,200.5^{a}$	14.3^{ab}	55.9^{ab}	36.9^{abc}	39.28^{a}	348^{a}	580^{a}
S.D.[3]	–	151.75	564.98	7.43	21.85	2.66	3.73	152.41	253.91
Overall									
2003	32.8	137.6^{a2}	575.4^{a}	15.3^{a}	59.0^{a}	36.7^{a}	37.5^{a}	161.2^{a}	268.7^{a}
2004	n/a	154.8^{a}	594.4^{a}	16.4^{a}	50.4^{b}	36.1^{a}	36.3^{a}	155.6^{a}	258.9^{a}
S.D.[3]	–	88.29	317.63	3.58	8.44	1.51	2.30	92.69	154.43

[1] Standard deviation; [2] In a column, means with the same letter are not statistically different ($P < 0.05$) according to Least Significant Test; [3] Least significant differences for $P < 0.05$; n/a: a trunk diameter was not determined for E_4 plantation in 2004.

Seed weight (based in 200 seed) was significantly greater in 2003 than 2004 ($P < 0.05$) (Table 3). Other traits showed no significant ($P < 0.05$) differences between years.

3.2. Yield components. Results between populations

The yield components of two moringa cultivars are presented in Table 4. The cultivar PKM-1 had higher seed yield than African cultivar and when 200 seeds were weighed, they were heavier than African cultivar too, contributing to higher oil per tree and oil per ha. Yields of oil per tree and oil per ha were 127 g and 72 kg, and 212 g and 121 kg for kernels produced by trees of PKM-1 and the African cultivar, respectively.

3.3. Fatty acid composition. Results within a population

No matter the plantation or year of seed production, no significant ($P < 0.05$) differences between fatty acid compositions were detected when oils of PKM-1 cultivar trees were compared (Table 5).

3.4. Fatty acids composition. Results between populations

Fatty acid composition of seeds collected from trees of the PKM-1 and African cultivars are shown in Table 5. In essence, both cultivars produced oil with practically identical fatty acid composition. The monounsaturated ω-9 oleic (18:1) fatty acid was the main one for both cultivars (more than 70% of total). Only the polyunsaturated ω-6 linoleic (18:2) fatty acid of the African genotype trees had a small but significantly ($P < 0.05$) higher content than that of PKM-1. All other fatty acid percentages were not significantly ($P < 0.05$) different between oils of the two cultivars.

4. Discussion

4.1. Seed and oil's yield components

Until now essentially all moringa has been grown in plantations smaller than one hectare, and with a wide range of plant density, making yield comparisons between this study and earlier reports difficult. However, in one report from the Tamil Nadu Agri-

Table 4
Yield and yield components of two different genotypes of moringa.

Trees	Trunk	Pods	Seeds			Kernel		Oil	
	Diameter	Per tree	Yields	Quantity	Weight	Weight	Oil	Yields	
	cm	Quantity	g per tree	Per pod	g per 200 seeds	g per 50 kernels	(%)	g per tree	kg per ha
PKM-1 population (D_5)									
D_5-1	32.5	100	400	16.00	50.0	36.4	34.77	101.25	232
D_5-2	32.5	214	1150	17.25	62.3	35.1	35.20	284.17	674
D_5-3	26.5	167	350	8.57	48.9	37.1	37.48	97.34	219
D_5-4	36.00	139	550	14.63	54.1	33.0	35.76	129.81	328
D_5-5	–	124	550	16.43	54.0	36.7	37.80	152.60	346
D_5-6	37.00	85	350	13.18	62.5	36.7	35.91	92.25	209
D_5-7	45.5	222	750	14.05	48.1	37.2	39.63	221.14	495
D_5-8	30.0	127	550	14.51	59.7	36.3	37.90	151.33	347
D_5-9	27.0	23	150	27.12	48.1	36.7	38.58	42.48	96
D_5-10	35.0	120	350	14.23	41.0	35.6	37.27	92.88	217
D_5-11	37.0	102	400	15.59	50.3	35.6	40.68	115.86	271
D_5-12	–	25	150	21.20	56.6	30.1	37.30	33.68	93
D_5-13	32.0	102	550	18.50	58.3	35.54	36.22	141.60	332
Average	33.433	119.23	480.77	16.25	48.33	33.00	37.27	127.41	296.85
S.D.[1]	5.33	59.56	261.84	4.40	6.38	1.97	1.72	67.65	156.99
Africa population (E_5)									
E_5-1	40	208	400	8.76	43.9	32.6	33.28	86.79	222
E_5-2	32	74	350	21.16	44.7	35.7	37.21	92.99	217
E_5-3	32	98	550	18.43	60.9	31.3	33.77	116.27	309
E_5-4	25	97	150	5.66	54.6	35.7	36.15	38.72	90
E_5-5	31	110	350	12.31	51.7	37.4	35.25	92.28	206
E_5-6	44	53	200	14.92	50.6	36.4	36.83	53.62	123
E_5-7	27	81	150	9.70	38.2	31.1	37.63	35.11	94
E_5-8	35	145	350	9.60	50.3	33.0	33.22	76.74	194
E_5-9	29	161	350	11.06	39.3	35.7	38.10	95.21	222
E_5-10	38	114	350	13.41	45.8	34.9	33.28	81.30	194
E_5-11	43	59	200	13.86	48.9	35.0	39.16	54.82	130
E_5-12	40	18	150	34.94	47.7	32.5	37.57	36.63	94
E_5-13	33	36	300	35.92	46.4	34.3	37.23	76.62	186
Average	34.54	96.46	296.15	16.13	47.92	34.00	36.05	71.91	175.46
S.D.[1]	6.05	52.68	119.83	9.48	6.08	2.00	2.07	25.90	65.21
Overall									
PKM-1	33.7	119.2	481	16.2	53.4	35.5	37.3	127	296
Africa	34.5	96.5	296	16.1	47.9	34.3	36.1	72	176
S.D.[1]	562	56.30	220.59	7.24	6.71	2.05	1.96	57.57	133

[1] Standard deviation.

cultural University (Suthanthirapandian et al., 1992), where PKM-1 was selected, under a high density plantation design similar to that used in the Argentine study, it produced 220–250 pods per tree. Just one tree of PKM-1 tested herein produced those many pods in both years; the E_4-9 tree showing not just superior annual yields compared with the earlier report, but a consistency of production from year to year. Two other trees in this study reached the previously reported high-yield range, but just in one of the two years tested (Table 3). However, the average production of 137.5 pods per tree of PKM-1 in Catamarca's E_4 plantation on its second year of bearing was similar to the 150 pods per tree reported by Suthanthirapandian et al. (1992), for PKM at Periyakulam, India.

As moringa in India is cultivated almost exclusively for fresh pod production under traditional low population density, little information is available about seed and oil yield per tree under high-density orchard design. However, we can compare the results found herein with that from other PKM-1 high-density orchards established by the author (unpublished data). Oil yields per tree, measured on E_4 (year 2003) were 33% higher than their produced by PKM-1 cultivar trees of two orchards located in the free frost areas of Anta Muerta

Table 5
Fatty acids' composition difference: between years within a population, and between populations.

Year	Plantation	Fatty acids											
		14:0	16:0	16:1	18:0	18:1	18:2	18:3	20:0	20:1	22:0	22:1	24:0
% of total fatty acids													
Between years of two PKM-1 populations													
2003	E_4	0.10^{a1}	5.70^{a}	1.50^{a}	5.68^{a}	72.65^{a}	0.60^{a}	0.20^{a}	3.73^{a}	2.35^{a}	6.05^{a}	0.10^{a}	1.05^{a}
2004	D_5	0.13^{a}	5.88^{a}	1.40^{a}	5.63^{a}	73.00^{a}	0.60^{a}	0.18^{a}	3.68^{a}	2.48^{a}	5.88^{a}	0.13^{a}	1.05^{a}
S.D.[2]	–	0.06	0.09	0.48	0.66	2.88	0.14	0.06	0.69	0.28	0.51	0.06	0.19
Between PKM-1 and Africa populations													
PKM-1	D_5	0.13^{a1}	5.88^{a}	1.40^{a}	5.63^{a}	73.00^{a}	0.60^{b}	0.18^{a}	3.68^{a}	2.48^{a}	5.88^{a}	0.13^{a}	1.05^{a}
Africa	E_5	0.10^{a}	5.58^{a}	1.08^{a}	5.93^{a}	72.32^{a}	0.73^{a}	0.20^{a}	3.83^{a}	2.13^{a}	6.50^{a}	0.10^{a}	1.15^{a}
S.D.[2]	–	0.06	0.68	0.54	1.76	3.63	0.12	0.06	0.85	0.37	0.83	0.06	0.19

[1] In a column, means with the same letter are not statistically different ($P < 0.05$) according to Least Significant Test; [2] Least significant differences for $P < 0.05$.

(22° 53′ South Latitude), Salta, Argentina, and Las Conchas (17° 24′ South Latitude), Santa Cruz, Bolivia, which both yielded 121 g of oil per tree on their second bearing season. In both cases, the orchard design and the tree's age were coincident with those of Catamarca, but both plantations were not irrigated. In addition, the oil yield per tree (127 g) of D_5 plantation was higher than that of 98 g obtained in Las Conchas with an orchard with the same cultivar, plantation design and tree age. Although these two areas are frost-free, both have an annual rain-free dry-season of up to six months, which is coincident with the cold-season of Catamarca. During the dry-season in Salta and Santa Cruz, trees lost part of their green biomass and even a number of woody branches, significantly less damage than trees exposed to frost in Catamarca. Although ratooning was practiced in the frost free regions, trees still had some branches and leaves below the point of pruning. These trees, located in the tropics area, at Anta Muerta and Las Conchas locations, cannot take advantage of these leaves until the rainy season arrives. However, because irrigation is used in Catamarca, plants receive water and begin growing as soon as the cold-season ends.

PKM-1 trees did not show an increased seed and oil yields from age one to two (plantation E_4, 2003 and 2004) ($P < 0.05$). This result was likely due to weather. Frost is a typical characteristic of the Arid Chaco's winter; the site of the experiment has a chance of a year without frost of just 7.7%, and both 2003 and 2004 years had typical winters, including a number of frosty days (Table 1). Moringa is a tropical plant and is damaged by temperatures below the freezing point. Frost occurred in both years of this study, and killed leaves and stems down to a distance of 30–120 cm above ground level. As the dates between the last frost and the early frost of each year determine the length of each growing season, Table 1 shows that difference between frost dates during the two years of this study resulted in a shorter growing season for 2004. The plant cycle of 2003–2004 had 50 fewer growing days than the 2002–2003 cycle (Table 1), reducing both the length of the vegetative growing cycle and the length of the reproductive cycle.

Weight of 200 seeds was the only yield component which differed significantly ($P < 0.05$) between years 2003 and 2004. The decrease in seed weight in 2004 could be related to total rainfall during the October–April period of each growing season as well as to the shorter growing season. From October 2002 to April 2003 304 mm of rain fell, while from October 2003 to April 2004 only 219 mm fell (Table 1). The same irrigation schedule was used during both years, so it is possible the 28% more precipitation which occurred in the first year favored larger seed size. Drought was reported as one of most visible factors that have affected a number of moringa oil physical and chemical characteristics, including seed weight and oil yield (Anwar et al., 2006).

No significant ($P < 0.05$) differences in seed yield per tree or in oil yield per tree between years were found when all trees were compared, but when individual trees were compared, most of them showed important variations in both seed and oil per tree yields. Within-plant variation in seed yield between the years ranged from <15% to 231%; within-plant variation in oil per tree ranged from <15% to 208%. It is interesting to note that tree E_4-9, which had significantly ($P < 0.05$) higher seed and oil per tree yields than the others, also varied <15% for both of these traits from year to year, adding to the interest in preserving it for future breeding and production purposes.

The variation between plants suggests significant genetic variation within the PKM-1 cultivar. Much variation within this cultivar has previously been found in India (Suthanthirapandian et al., 1989). These workers measured a number of traits on individual plants of PKM-1. Much variation was found; number of flowers per inflorescence varied from 19 to 126, pod weight ranged from 25 to 232 g, and pods per plant from 1 to 155. Other authors reported an off-type tree of around 40–45% for a typical plantation of southern India, where around 5000 ha has been implanted with this cultivar (Anbarassan et al., 2001). The magnitude of the standard deviation found for the PKM-1 and Africa cultivar tree yield's components indicates that the highest levels of genetic diversity can be expected within the PKM-1 populations than in the African population. This finding is supported by Muluvi et al. (1999) who reported on a genetic analysis of moringa using amplified fragment length polymorphism markers. A number of moringa populations collected in Africa and India were grown in Tamil Nadu, India and compared. Greater genetic diversity was found within populations from India, than within populations from East Africa. This comparative smaller genetic diversity of the Africa genotypes could mean that this population developed from a very limited germplasm base introduced into Africa from India.

The higher seed per tree, oil per tree yield, and weight of 200 per seed detected on trees of the PKM-1 cultivar, compared with those of the African cultivar, suggest that the genotype from India has more likelihood of economic usefulness in the Arid Chaco. The PKM-1 trees produced 63%, and 76% more seed per tree and oil per tree, respectively, than the African trees. These first results obtained in the Arid Chaco, plus the reported greater genetic variability of Indian germplasm over African germplasm, point to more short-term progress being made by focusing on germplasm from India.

A genetic characteristic of PKM-1 is to show a great precocity of production compared with common cultivars formerly used by the growers ago (Rajangam et al., 2001). PKM-1 trees begin producing six months after seeding. Other genotypes produce their first harvest after a year, and the early harvests are generally low but gradually increase until trees are four years old. In this study, since these two genotypes were compared at 6–10 months of age, the yield advantage of PKM-1 could be attributed to this genetic pattern (Lalas and Tsaknis, 2002; Rajangam et al., 2001).

Results obtained in Catamarca trials suggest that frost could replace in some manner the annual needs for pruning to stimulate the next crop, reducing production costs. This 'free' pruning provided by light frosts also maintains the plants in a smaller form, facilitating hand harvest.

In India, since the seed propagated PKM genotype cultivars (PKM-1 and PKM-2) were released, they are namely annual moringas to be differentiated of all other cultivars denominated perennial moringas, based on the PKM genotypes precocity of bearing and needs of receiving on an annual base, a severe pruning practice called ratooning. After the harvest, the trees are cut down to 1 m height from the ground level to stimulate new shoots develop and start bearing fourth or five months after were pruned (Rajangam et al., 2001). The increase yield effect of the ratooning practice on PKM-1 genotype trees has been demonstrated in a number of trials. In one of them conducted at the Horticultural Research Station, Periyakulam, Tamil Nadu, India, some traits of annual moringa PKM genotype trees on the second bearing year, between trees cut down to 1 m high from the ground level for ratooning and non ratoon treatment trees were compared, showing the ratoon crop a significant ($P < 0.01$) higher pods per tree (150 pods per tree) than that produced 68 pods per tree without ratooning practice (Suthanthirapandian et al., 1992).

4.2. Fatty acids composition

The lack of statistically significant ($P < 0.05$) difference in oil percentage and in fatty acid composition of PKM-1 genotypes between years and between trees, and the small standard deviation for these traits suggest that a genetic improvement program will be less effective if focused on these two characteristics than on any one of the other yield's components herein considered. The average oil percent and the fatty acid composition of seeds from PKM-1 genotypes' trees collected on trials E_4 (2003 and 2004) and D_5

(Tables 3 and 4), are very close to the 38.3% and 71.1% of oil and oleic fatty acid content, respectively, reported for seeds of this cultivar growing in India (Lalas and Tsaknis, 2002). In addition, the PKM-1 cultivar trees oil percentage obtained herein, were in agreement with that of 36% and 37%, found in the kernels of the same genotype trees' seeds collected in Las Conchas and Anta Muerta plantations, respectively. Similarly, oil and oleic fatty acid contents of seeds from the Africa genotype trees were close to the 35.7% and 73.6%, respectively, reported for the Mbololo cultivar selected in East Africa (Tsaknis et al., 1999). Although between Africa and PKM-1 genotype populations, the linoleic and the linoleic + linolenic (18:3) fatty acid content differences were small, PKM-1 cultivar trees had 22% and 19% more contents for linoleic and linoleic + linolenic, respectively, both means were significantly ($P < 0.05$) different (data not shown for linoleic + linolenic). These contents need to be closely monitored and can be an important difference between the oils of both genotypes, because one of the advantages found by the cosmetic industry on the moringa oil over the other oleic fatty acid source is their oxidative stability based on their content of PUFA (polyunsaturated fatty acids) lower than 1% of the total fatty acid content (Kleiman et al., 2008). A major advantage of moringa oil over other oleic fatty acid sources is their oxidative stability.

In conclusion, oil percentage and fatty acid composition, including oleic fatty acid yields per tree of the two moringa cultivars grown in the Arid Chaco were similar or even better than that reported for other ecosystems where these cultivars of moringa have been cultivated. This study showed that climatic characteristics such as rain and date and temperature-extreme of the winter frost, impact length of the growing cycle and growth rates, affecting the seed weight. This significant ($P < 0.05$) difference between years within the PKM-1 genotype population on seed weight, and the standard deviation magnitude of the seed per tree yield, shows an important potential to include it in a selection program to obtain superior genotypes better adapted to the Arid Chaco ecosystem, and increase the yields of seed per oil per hectare.

The oil yields obtained in this study with PKM-1 compare favorably to those obtained with the same cultivar growing in the tropic regions without frost, but without irrigation. However, economic aspects, including irrigation and pruning costs, need to be evaluated.

An interesting benefit in this moringa trial was the frost effect on PKM-1, suggesting not just the potential of growing moringa for seed and oil in the Arid Chaco ecosystem, but that the light frosts experienced in this region can substitute for the expensive ratooning per pruning practice used elsewhere.

This study indicates that moringa tree oil can be produced reasonably well under irrigated conditions in the Arid Chaco ecosystem of northwestern Argentina. However, additional studies are needed to determine factors affecting moringa yields, including potential interactions of genotype × environment on seed per tree production, before making any recommendation about the economic potential of moringa as a new crop for this region. However we need to emphasize that it is a group of selected plants which produced reasonable well, if all plants in each plantation were included, yields might not look so good.

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