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Biochemical Heterogeneity in Seedling-Grown Argania spinosa Orchard: Toward Improved Oil and By-Product Quality

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Introduction

Taxonomy

Clade: Angiosperms
Order: Ericales
Family: *Sapotaceae*
Genus: *Sideroxylon* (syn. *Argania*)
Species: *Sideroxylon spinosum* (syn. *Argania spinosa*)

Introduction

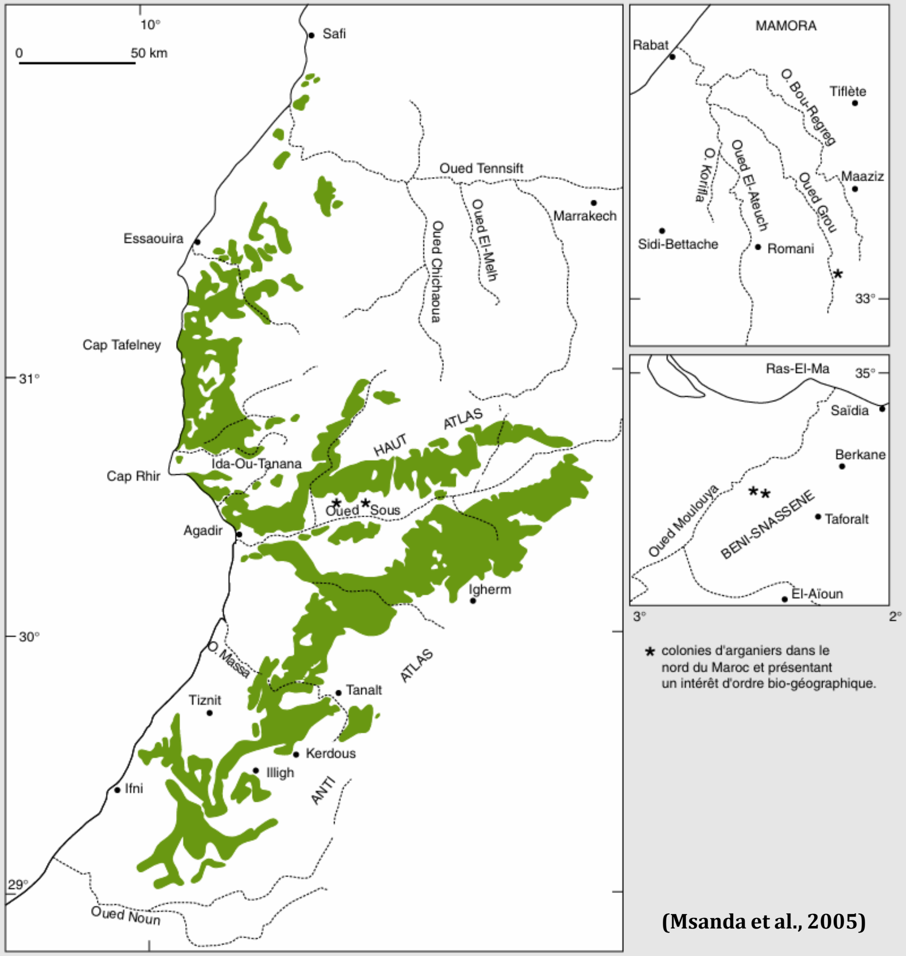
Reproductive system :

- Strict allogamy
- Complex pollen incompatibility
- Essentially entomophilic pollination

Introduction

Geographical distribution

- **Endemic to central Morocco.**
  Relict populations, sparsely distributed in the pre-Saharan regions.
  Introduced in Tunisia, Spain, and Israel.



(Msanda et al., 2005)

Introduction

Ecology:

- Spontaneous in the infra-Mediterranean and thermo-Mediterranean bioclimatic zones (0–1200 m above sea level; Delimitation: 28–32° N (latitude) and 8–10° W (longitude)).

- Emblematic and key species, playing a central role in several ecosystems and plant communities.

Introduction

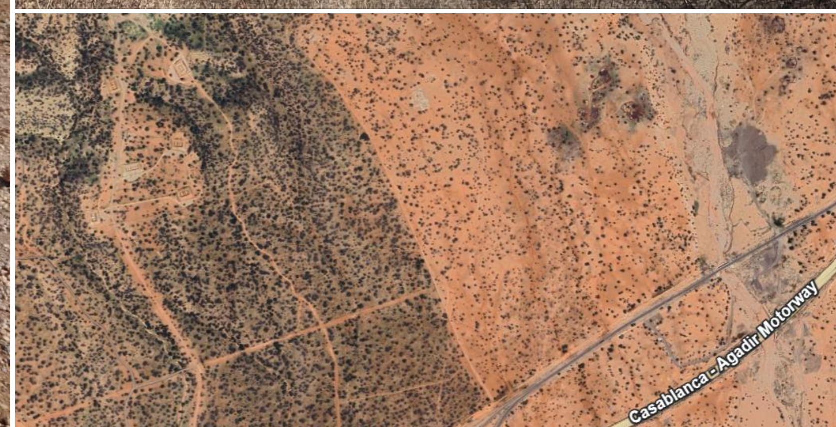
Economic significance

- Agro-sylvo-pastoral exploitation
- Crucial to the local economy, it produces one of the most prized oils in the world.
- Valuable byproducts include press cake and nutshells.

Introduction

Threats

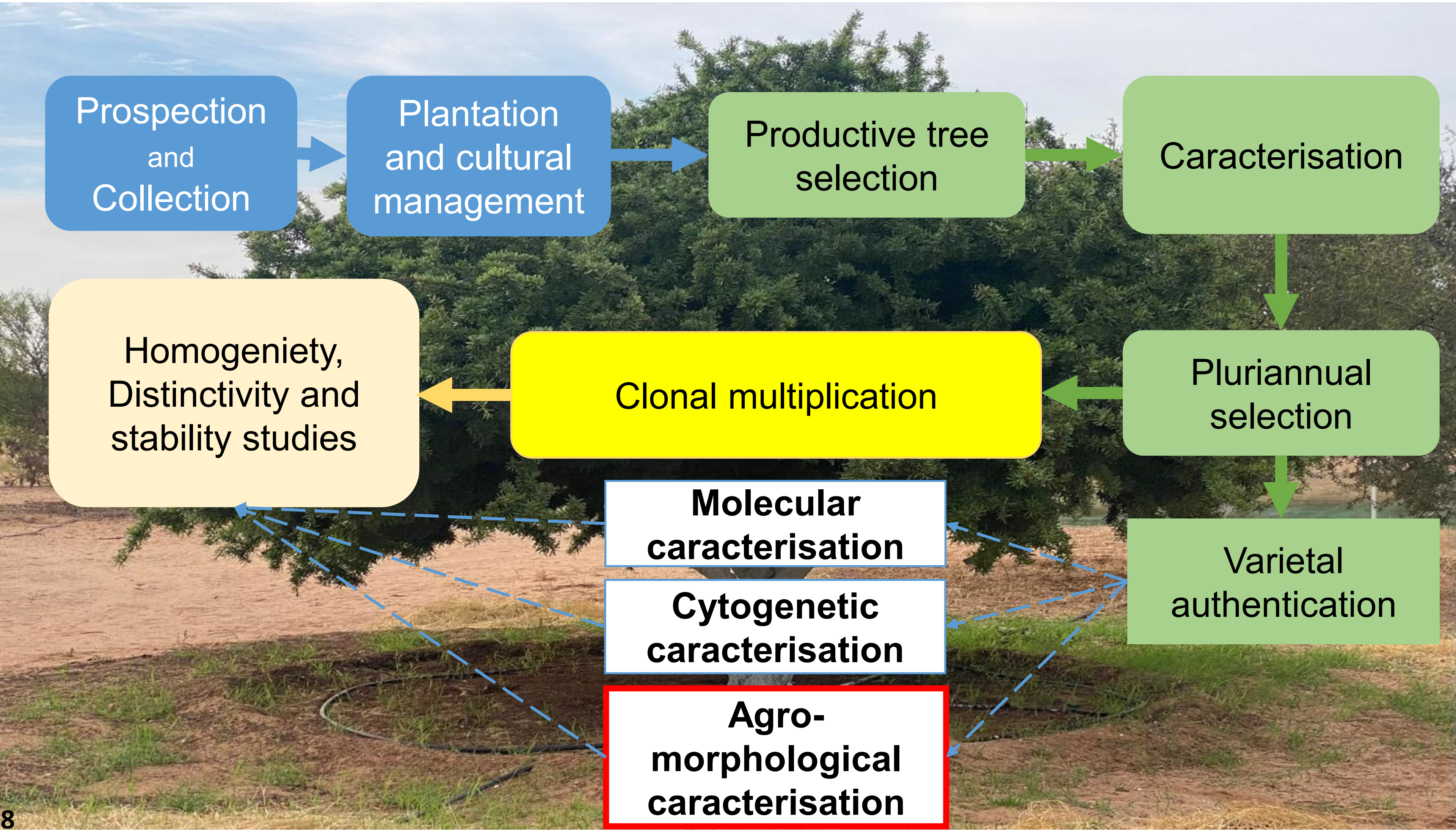
- Endangered due to overexploitations and climate change.



Introduction

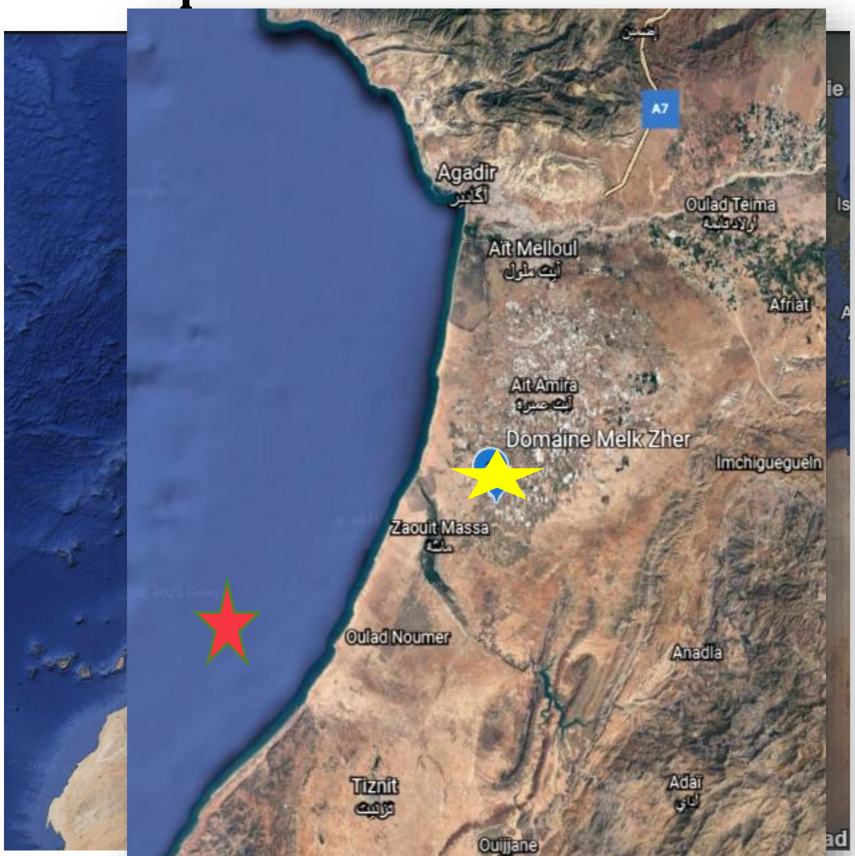
Assisted plantations and breeding for intensive culture

Introduction



Materials and methods

Site Experimentation and Plant material



Melk Zhar Experimental Domain

Tree sources are cultivated under uniform environmental and agronomic management

Materials and methods

Materials and methods

Fatty acid compositions

GC
Gas Chromatography – Flame Ionization Detection

Free amino acids

LC/MS
Liquid Chromatography coupled with Tandem Mass Spectrometry

Elemental composition

ICP-OES
Inductively Coupled Plasma–Optical Emission Spectroscopy

Protein Content

Kjeldahl Analysis
Protein=Nitrogen×5.4

Descriptive statistics, and means comparison were done using packages compiled with R software 4.5.0.

Results and discussions

Table 1. Trace element variation across genotypes in argan almonds

Genotypes code	Pb mg/Kg	Ni mg/Kg	Cr mg/Kg	Ba mg/Kg
1	0.000 ± 0.000 e	0.467 ± 0.007 f	0.305 ± 0.003 cd	0.913 ± 0.004 g
2	0.189 ± 0.002 a	1.033 ± 0.000 a	0.998 ± 0.000 a	1.245 ± 0.000 d
4	0.000 ± 0.000 e	0.418 ± 0.005 g	0.328 ± 0.007 c	0.970 ± 0.002 f
5	0.063 ± 0.001 d	0.690 ± 0.006 b	0.278 ± 0.008 d	0.781 ± 0.010 h
6	0.000 ± 0.000 e	0.236 ± 0.006 j	0.222 ± 0.009 f	1.908 ± 0.023 a
7	0.000 ± 0.000 e	0.316 ± 0.005 i	0.219 ± 0.001 f	1.055 ± 0.003 e
8	0.000 ± 0.000 e	0.641 ± 0.007 c	0.307 ± 0.021 cd	1.434 ± 0.009 b
9	0.000 ± 0.000 e	0.531 ± 0.013 e	0.317 ± 0.004 c	1.855 ± 0.007 a
10	0.098 ± 0.002 c	0.568 ± 0.005 d	0.401 ± 0.009 b	1.294 ± 0.014 c
13	0.000 ± 0.000 e	0.377 ± 0.008 h	0.248 ± 0.007 e	0.773 ± 0.011 h
16	0.172 ± 0.004 b	0.542 ± 0.002 de	0.340 ± 0.003 bc	0.958 ± 0.005 f
Means	0.047 ± 0.001 ***	0.529 ± 0.006 ***	0.360 ± 0.007 ***	1.199 ± 0.008 ***

Table 2. Variation in sodium content in argan almonds

Genotypes code	Na mg/Kg
1	425.311 ± 0.454 g
2	465.527 ± 0.714 c
4	370.893 ± 0.160 i
5	433.732 ± 0.396 f
6	326.393 ± 1.088 j
7	438.735 ± 0.412 e
8	449.094 ± 0.068 d
9	504.756 ± 0.521 b
10	554.443 ± 0.254 a
13	309.764 ± 3.621 k
16	401.824 ± 0.709 h
Means	425.497 ± 0.763 ***

Results and discussions

Table 3. Oligo-element variation across genotypes in argan almonds

Genotypes code	Mo mg/Kg	Zn mg/Kg	Fe mg/Kg	B mg/Kg	Mn mg/Kg	Cu mg/Kg
1	0.737 ± 0.009 d	19.055 ± 0.092 d	28.061 ± 0.228 g	17.635 ± 0.092 h	14.324 ± 0.005 g	1.914 ± 0.003 j
2	0.949 ± 0.002 b	23.511 ± 0.225 a	39.382 ± 0.000 b	17.428 ± 0.000 h	28.977 ± 0.000 a	6.948 ± 0.000 a
4	0.985 ± 0.007 a	19.197 ± 0.034 d	37.627 ± 0.598 c	19.900 ± 0.210 cd	19.799 ± 0.956 f	4.774 ± 0.051 d
5	0.259 ± 0.003 g	19.378 ± 0.003 cd	25.837 ± 0.230 i	19.508 ± 0.046 de	23.418 ± 0.138 c	2.241 ± 0.003 h
6	0.745 ± 0.004 cd	18.450 ± 0.002 e	25.898 ± 0.104 i	20.669 ± 0.059 b	22.244 ± 0.153 cde	3.362 ± 0.005 f
7	0.762 ± 0.000 c	16.180 ± 0.013 f	26.639 ± 0.010 h	19.137 ± 0.001 ef	21.939 ± 0.005 de	1.454 ± 0.002 k
8	0.948 ± 0.004 b	19.832 ± 0.114 c	35.344 ± 0.005 d	19.293 ± 0.017 e	21.095 ± 0.024 e	2.308 ± 0.038 g
9	0.936 ± 0.009 b	20.730 ± 0.398 b	29.174 ± 0.070 f	23.529 ± 0.011 a	22.512 ± 0.042 cd	5.253 ± 0.010 c
10	0.686 ± 0.006 e	23.008 ± 0.018 a	46.594 ± 0.507 a	20.096 ± 0.038 c	25.450 ± 0.094 b	5.814 ± 0.039 b
13	0.665 ± 0.005 e	17.979 ± 0.094 e	31.943 ± 0.256 e	18.810 ± 0.299 f	22.931 ± 0.115 cd	2.075 ± 0.008 i
16	0.547 ± 0.008 f	20.948 ± 0.074 b	39.214 ± 0.016 b	18.175 ± 0.005 g	19.862 ± 0.058 f	3.811 ± 0.002 e
Means	0.747 ± 0.005 ***	19.843 ± 0.097 ***	33.247 ± 0.184 ***	19.471 ± 0.071 ***	22.050 ± 0.144 ***	3.632 ± 0.015 ***

Results and discussions

Table 4. Major element variation across genotypes in argan almonds

Genotypes code	P mg/Kg	Mg mg/Kg	Ca mg/Kg	K mg/Kg
1	3412.111 ± 0.503 e	1597.763 ± 1.032 e	1971.262 ± 0.711 g	3756.594 ± 0.713 k
2	3343.958 ± 0.088 f	1527.353 ± 0.527 g	2101.551 ± 0.734 d	4007.412 ± 0.874 g
4	2979.373 ± 0.865 i	1888.053 ± 0.099 b	1756.183 ± 1.188 i	3976.999 ± 0.165 h
5	3933.037 ± 0.277 a	2034.202 ± 0.594 a	2020.927 ± 0.133 e	4686.760 ± 0.357 b
6	3435.906 ± 0.150 d	1523.748 ± 0.529 g	3010.507 ± 0.733 a	3965.388 ± 0.883 i
7	2798.067 ± 0.723 j	1643.478 ± 1.295 c	2131.131 ± 0.673 c	4235.065 ± 0.300 f
8	3777.083 ± 0.038 c	1429.184 ± 0.655 j	2012.889 ± 0.612 f	3846.215 ± 1.359 j
9	3874.260 ± 1.076 b	1630.890 ± 3.917 d	2546.145 ± 3.016 b	4633.888 ± 2.465 c
10	3017.881 ± 0.202 h	1546.995 ± 0.322 f	1739.493 ± 1.595 j	4824.160 ± 0.513 a
13	2779.996 ± 3.353 k	1476.546 ± 0.955 h	1489.643 ± 2.217 k	4288.894 ± 0.924 e
16	3332.589 ± 0.880 g	1448.144 ± 0.410 i	1848.667 ± 2.055 h	4295.589 ± 1.996 d
Means	3334.933 ± 0.741***	1613.305 ± 0.939 ***	2057.127 ± 1.242 ***	4228.815 ± 0.959 ***

Results and discussions

Table 5. Protein content variation across genotypes in argan almonds

Genotypes code	Proteins %
1	20.900 ± 0.000 f
2	19.700 ± 0.000 i
4	19.375 ± 0.035 j
5	19.850 ± 0.071 h
6	22.000 ± 0.000 b
7	21.800 ± 0.000 c
8	22.400 ± 0.000 a
9	20.700 ± 0.000 g
10	21.100 ± 0.000 d
13	19.800 ± 0.000 h
16	21.000 ± 0.000 e
Means	20.784 ± 0.010 ***

Results and discussions

Table 6. Amino acids compositions variation across genotypes in argan almonds

Genotypes code	Lysin %	Methionin %	Phenylalanin %	Prolin %	Serin %	Threonin %	Tyrosin %	Valin %
1	0.263 ± 0.000 k	0.075 ± 0.000 i	0.271 ± 0.000 i	0.647 ± 0.001 i	0.693 ± 0.001 f	0.515 ± 0.001 i	0.323 ± 0.000 c	0.234 ± 0.000 k
2	0.440 ± 0.000 f	0.233 ± 0.000 a	0.516 ± 0.000 b	0.854 ± 0.000 c	0.672 ± 0.000 h	0.598 ± 0.000 g	0.450 ± 0.000 a	0.401 ± 0.000 d
4	0.418 ± 0.001 g	0.090 ± 0.000 g	0.378 ± 0.001 e	0.774 ± 0.001 e	0.683 ± 0.001 g	0.621 ± 0.001 f	0.417 ± 0.001 b	0.290 ± 0.001 h
5	0.339 ± 0.001 j	0.121 ± 0.000 d	0.377 ± 0.001 e	0.594 ± 0.002 j	0.564 ± 0.002 j	0.425 ± 0.001 k	0.292 ± 0.001 e	0.248 ± 0.001 j
6	0.569 ± 0.001 c	0.115 ± 0.000 e	0.357 ± 0.000 g	0.741 ± 0.001 h	0.724 ± 0.001 e	0.587 ± 0.001 h	0.254 ± 0.000 f	0.339 ± 0.000 g
7	0.374 ± 0.000 h	0.049 ± 0.000 j	0.303 ± 0.000 h	1.013 ± 0.001 b	0.592 ± 0.000 i	0.644 ± 0.000 e	0.233 ± 0.000 i	0.378 ± 0.000 f
8	0.524 ± 0.000 e	0.078 ± 0.000 h	0.363 ± 0.000 f	0.756 ± 0.000 f	0.808 ± 0.001 c	0.725 ± 0.000 d	0.220 ± 0.000 j	0.390 ± 0.000 e
9	0.686 ± 0.000 b	0.111 ± 0.000 f	0.410 ± 0.000 c	0.808 ± 0.001 d	0.744 ± 0.000 d	0.777 ± 0.001 c	0.240 ± 0.000 h	0.455 ± 0.000 c
10	0.877 ± 0.000 a	0.151 ± 0.000 b	0.529 ± 0.000 a	1.031 ± 0.000 a	0.985 ± 0.000 a	0.874 ± 0.000 b	0.313 ± 0.000 d	0.607 ± 0.000 a
13	0.357 ± 0.000 i	0.048 ± 0.000 k	0.243 ± 0.000 j	0.586 ± 0.001 k	0.550 ± 0.001 k	0.505 ± 0.000 j	0.093 ± 0.000 k	0.259 ± 0.000 i
16	0.562 ± 0.000 d	0.133 ± 0.000 c	0.404 ± 0.000 d	0.750 ± 0.001 g	0.933 ± 0.001 b	1.065 ± 0.001 a	0.249 ± 0.000 g	0.545 ± 0.000 b
Means	**0.492 ± 0.000 *** **	**0.110 ± 0.000 *** **	**0.377 ± 0.000 *** **	**0.778 ± 0.001 *** **	**0.723 ± 0.001*** **	**0.667 ± 0.001*** **	**0.280 ± 0.000 *** **	**0.377 ± 0.000 *** **

Results and discussions

Table 6 (continue). Amino acids compositions variation across genotypes in argan almonds

Genotypes code	Glycine %	Alanin %	Arginin %	Aspartate %	Glutamate %	Histidin %	Isoleucin %	Leucin %
1	1.901 ± 0.002 d	7.194 ± 0.008 b	0.598 ± 0.001 k	1.997 ± 0.002 h	2.447 ± 0.003 i	0.019 ± 0.000 k	0.079 ± 0.000 k	0.509 ± 0.001 k
2	1.447 ± 0.001 i	3.087 ± 0.002 f	0.911 ± 0.001 g	2.302 ± 0.001 f	3.605 ± 0.002 d	0.107 ± 0.000 f	0.208 ± 0.000 c	0.911 ± 0.001 d
4	1.563 ± 0.003 g	2.249 ± 0.004 i	0.884 ± 0.002 h	3.058 ± 0.006 a	3.967 ± 0.008 b	0.093 ± 0.000 h	0.150 ± 0.000 g	0.808 ± 0.002 g
5	1.208 ± 0.004 j	7.065 ± 0.024 c	0.656 ± 0.002 j	1.612 ± 0.005 j	2.505 ± 0.008 h	0.098 ± 0.000 g	0.126 ± 0.000 h	0.631 ± 0.002 h
6	1.621 ± 0.002 f	5.768 ± 0.006 d	1.037 ± 0.001 d	2.016 ± 0.002 g	3.284 ± 0.003 f	0.208 ± 0.000 b	0.197 ± 0.000 d	0.886 ± 0.001 e
7	1.518 ± 0.001 h	5.784 ± 0.003 d	1.013 ± 0.001 e	2.678 ± 0.001 b	3.186 ± 0.002 g	0.053 ± 0.000 j	0.099 ± 0.000 j	0.584 ± 0.000 i
8	1.981 ± 0.001 c	5.250 ± 0.003 e	0.984 ± 0.001 f	2.324 ± 0.001 e	3.434 ± 0.002 e	0.143 ± 0.000 e	0.160 ± 0.000 e	0.875 ± 0.001 f
9	1.777 ± 0.001 e	2.903 ± 0.002 g	1.198 ± 0.001 b	2.494 ± 0.002 d	3.626 ± 0.002 c	0.176 ± 0.000 c	0.156 ± 0.000 f	1.006 ± 0.001 c
10	1.994 ± 0.000 b	0.000 ± 0.000 j	1.436 ± 0.000 a	3.053 ± 0.000 a	4.226 ± 0.000 a	0.279 ± 0.000 a	0.324 ± 0.000 a	1.235 ± 0.000 a
13	1.176 ± 0.001 k	7.245 ± 0.007 a	0.720 ± 0.001 i	1.943 ± 0.002 i	2.311 ± 0.002 j	0.089 ± 0.000 i	0.113 ± 0.000 i	0.561 ± 0.001 j
16	2.356 ± 0.002 a	2.448 ± 0.002 h	1.113 ± 0.001 c	2.579 ± 0.002 c	3.277 ± 0.003 f	0.165 ± 0.000 d	0.225 ± 0.000 b	1.029 ± 0.001 b
Means	1.686 ± 0.002 ***	4.454 ± 0.006 ***	0.959 ± 0.001 ***	2.369 ± 0.002 ***	3.261 ± 0.003 ***	0.130 ± 0.000 ***	0.167 ± 0.000 ***	0.821 ± 0.001 ***

Results and discussions

Table 6. Fatty acids compositions variation across genotypes in argan almonds

Genotypes code	Palmitic %	Stearic %	Oleic %	Linoleic %	Arachidic %
1	14.655 ± 0.742 b	6.195 ± 0.219 c	49.755 ± 0.544 bc	28.575 ± 0.601 d	0.350 ± 0.057 abc
2	14.110 ± 0.071 bc	5.680 ± 0.127 d	47.550 ± 0.141 cde	31.895 ± 0.361 b	0.385 ± 0.035 ab
4	13.970 ± 0.453 bc	6.790 ± 0.071 b	48.395 ± 0.049 cde	29.890 ± 0.608 cd	0.500 ± 0.028 a
5	12.630 ± 0.212 d	5.715 ± 0.120 cd	51.055 ± 0.191 ab	29.715 ± 0.544 cd	0.390 ± 0.014 ab
6	13.095 ± 0.007 cd	7.300 ± 0.156 a	47.120 ± 0.184 de	31.390 ± 0.014 bc	0.510 ± 0.014 a
7	14.325 ± 0.134 bc	5.165 ± 0.106 e	49.290 ± 0.212 bcd	30.225 ± 0.078 cd	0.395 ± 0.007 ab
8	15.055 ± 0.007 b	6.745 ± 0.035 b	47.950 ± 0.410 cde	29.345 ± 0.021 cd	0.460 ± 0.099 ab
9	14.395 ± 0.502 bc	6.705 ± 0.021 b	41.825 ± 1.761 f	35.955 ± 0.983 a	0.490 ± 0.028 a
10	14.725 ± 0.375 b	5.805 ± 0.106 cd	52.565 ± 0.969 a	26.305 ± 0.771 e	0.315 ± 0.007 bc
13	17.365 ± 0.078 a	5.150 ± 0.170 e	46.005 ± 0.191 e	30.725 ± 0.177 cd	0.320 ± 0.014 bc
16	14.115 ± 0.375 bc	6.740 ± 0.099 b	49.975 ± 0.219 abc	28.875 ± 0.728 d	0.110 ± 0.085 c
Means	14.404 ± 0.269 ***	6.181 ± 0.112 ***	48.317 ± 0.443 ***	30.263 ± 0.444 ***	0.384 ± 0.035 ***

Results and discussions

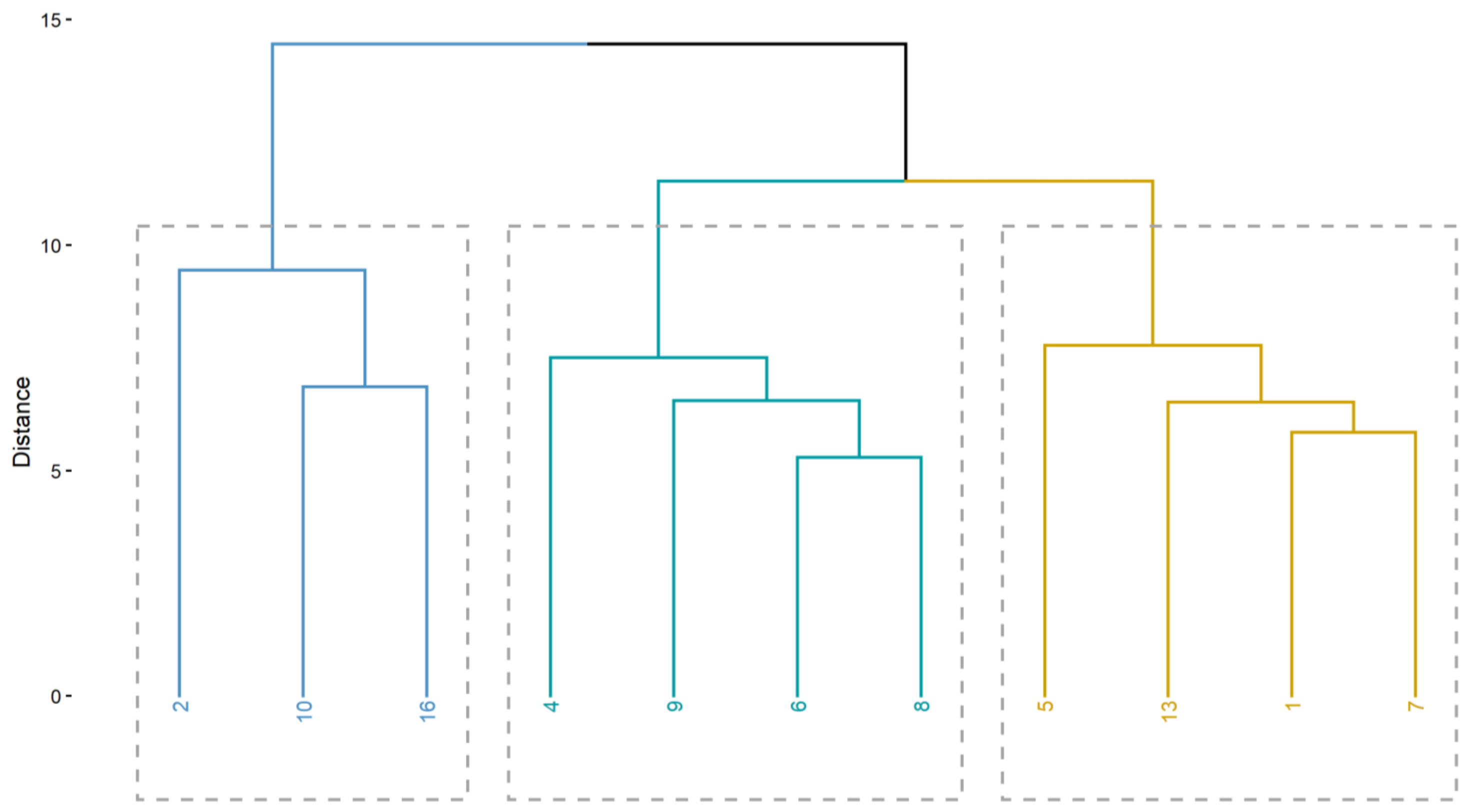


Figure 1. Dendrogram of the genotypes constructed from all measured variables

Results and discussions

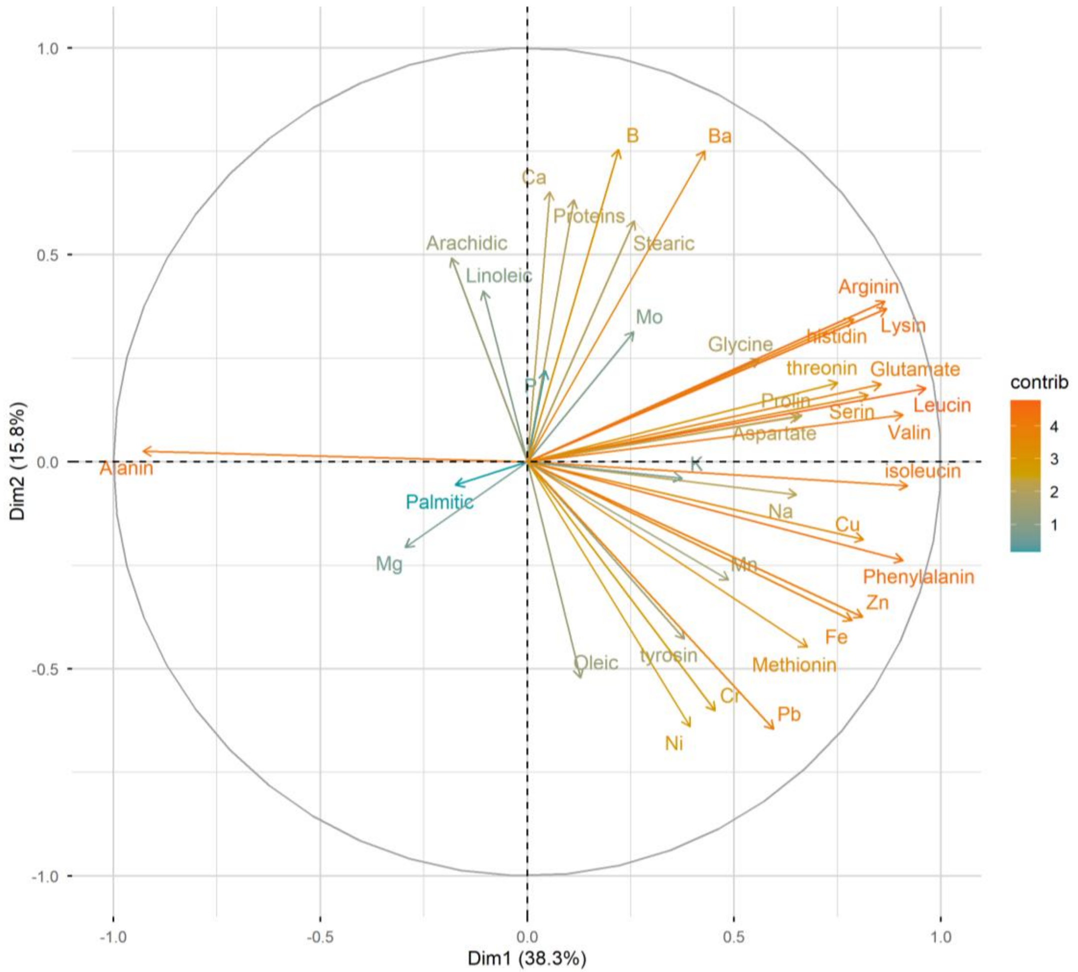


Figure 2. Principal Component Analysis (PCA) of all measured variables

Conclusions and recommendations

The biochemical composition of almonds suggests a strong genetic influence and directly influences both the quality of argan oil and the value of its by-products.

The chemical composition of argan kernels would affect the quality of argan oil (fatty acid composition) and the nutritional value of the press cake (minerals, amino acids, and protein content).

These results emphasize the importance of selecting elite genotypes for clonal propagation, ensuring consistent oil quality, sustainable cultivation, and independence from wild argan forest exploitation.

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Thank you for your attention!

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