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Original Research Paper

Functional Diversity Based on Morphometric Analysis and Identification of the Algerian Carob Tree (*Ceratonia siliqua* L.) Cultivars

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Abstract

Sixty-six carob accessions from 19 sites throughout Algeria were analysed by leaf, pod and seed characteristics to assess their genetic diversity and identify the Algerian carob cultivars that could be used as germplasm for breeding programs. We compared Algerian accessions with carobs from different Mediterranean countries, and the results showed a high level of morphological similarity between Algerian and Spanish carob pods. Analysis of variance (ANOVA) revealed highly significant differences ($p < 0.001$) between accessions for all the quantitative traits. Correlation analysis between variables indicated that seed yield could be improved by selecting light, thin and narrow carob pods. Multiple correspondence analysis explained a total variance of 30.22 % and illustrated three distinct leaf classes. Principal component analysis (PCA) proposed two main groups of variables, one based on seed performance and the other targeting pod potential. Hierarchical classification (HC) with seven clusters revealed considerable genetic diversity among the Algerian carob accessions studied, and indicated that the type of bioclimate did not influence their distribution, suggesting that morphometric traits are probably controlled more by genes that by bioclimate. Linear discriminant analysis (LDA), clustering and heatmap plotting identified 11 potential cultivars, 10 female and one hermaphroditic.

Key words: carob germplasm; characterisation; genetic diversity; identification; morphological analysis; statistical tools.

الملخص

تم تحليل ستة وستين مدخلاً من الخروب من 19 موقعًا في جميع أنحاء الجزائر من خلال خصائص الأوراق والقرون والبذور لتقييم تنوعها الجيني وتحديد أصناف الخروب الجزائرية التي يمكن استخدامها كأصول وراثية لبرامج التحسين. قارنا المدخلات الجزائرية بالخروب من بلدان البحر الأبيض المتوسط المختلفة ، وأظهرت النتائج مستوى عالٍ من التشابه المورفولوجي بين قرون الخروب الجزائرية والإسبانية. كشف تحليل التباين عن فروق ذات دلالة إحصائية بين المدخلات لجميع الصفات الكمية. أشار تحليل الارتباط بين المتغيرات إلى أنه يمكن تحسين محصول البذور عن طريق اختيار قرون الخروب الخفيفة والرقيقة والضيقة. أوضح تحليل المراسلات المتعددة تباينًا إجماليًا بنسبة 30.22 ٪ وأوضح ثلاث فئات أوراق متميزة. اقترح تحليل المكون الرئيسي مجموعتين رئيسيتين من المتغيرات ، واحدة تعتمد على أداء البذور والأخرى على القرون. أظهر التصنيف الهرمي المكون من سبع مجموعات تنوعًا جينيًا كبيرًا بين مدخالت الخروب الجزائرية التي تمت دراستها ، وأشار إلى أن نوع المناخ الحيوي لم يؤثر على توزيعها ، مما يشير إلى أن السمات المورفومترية ربما تتحكم فيها الجينات أكثر من المناخ الحيوي. حدد التحليل التمييزي الخطي والتجميع والتخطيط الحراري 11 صنفًا محتملاً من الخروب ، 10 إناث وواحد خنثى.

الكلمات المفتاحية : الخروب ، التوصيف ، التنوع الجيني ، التحديد ، التحليلات المورفولوجية ، الاختبارات الإحصائية

Introduction

The carob tree (*Ceratonia siliqua* L.) is a sclerophyllous, xerophilic, thermophilic, heliophilic and calcicolous species (Mahdad and Gaouar, 2016) belonging to the family Fabaceae. Genetic and fossil data support a pre-Mediterranean origin of the carob tree with the split between *C. oreothauma* and *C. siliqua* estimated at 6.4 Ma (Bessedik et al., 1984; Viruel et al., 2020), and its ancestors were likely distributed around the Tethys Sea during Paleogene times (Palamarev, 1989). However, its centre of diversification is well known and is indisputably the Mediterranean basin (Batlle and Tous, 1997; Melgarejo and Salazar, 2003; Viruel et al., 2020). This rustic agroforestry species plays a pivotal socio-economic and ecological role, particularly in dry regions and areas where desertification processes are occurring at significant magnitudes, especially in Algeria. It is usually found in regions with a Mediterranean climate (Baumel et al., 2018), but also in regions with a continental climate such as the Algerian steppe, where wild carob trees have been observed at an altitude of 1168 m in areas with temperatures regularly reaching – 10 °C (Mahdad and Gaouar, 2016).

All parts of the carob trees (i.e., roots, wood, bark, leaves, flowers and fruits) have economic value and considerable health benefits and can be used in several sectors. Its lateral roots, which are branched with numerous root hairs and extend over a length of 30 to 40 m (Tous, 1984), allow the tree to grow in rocky terrain with shallow soil and in arid conditions, which would be restrictive for other crops (Albanell, 1990). The wood of the carob tree, known as *carouge* (Rivière and Leco, 1900), is hard with a fine grain and is used in the manufacture of utensils and production of fuel (Batlle and Tous, 1997). The bark of the tree is used in tanneries, particularly in finishing and enamelling hides (Batlle, 1997) and is very rich in antioxidant substances (El Hajaji et al., 2011). Carob leaves have anticancer, antioxidant, bactericidal and anti-neurodegenerative properties (Corsia et al., 2002; El Hajaji et al., 2010; Meziani et al., 2015; Ben Othman et al., 2020; Abidar et al., 2020). El-Haskoury et al. (2015) discovered that carob honey has diuretic, natriuretic and kaliuretic activity without the side effects of hypokalaemia; the honey is also rich in bioactive molecules with antioxidant and anti-radical properties (El-Haskoury et al., 2018). Given its enormous economic interest, locust bean gum remains the most important product among those derived from the seed. It constitutes one third of the total weight of the seed (Jones, 1953). This mucilaginous gum, rich in galactomannan known under the code E-410, is used in the food industry as a thickener, stabiliser, binder and gelling agent or as a dispersing agent (Batlle and Tous, 1997). It is also used in printing, photography, textiles, pharmaceuticals, cosmetics, chemicals, petroleum, explosives and mixed feed (Tous et al., 2013). Furthermore, Ben Ayache et al. (2020) observed that the seeds demonstrate the most potent anticarcinogenic properties on all human cell carcinomas tested. Carob pods have traditionally been used as feed for ruminants (Louca and Papas, 1973) and non-ruminants (Sahle et al., 1992), but also for human consumption (Azab, 2017). Its pulp is used as a substitute for cocoa in the production of chocolate because it is less calorific and does not contain caffeine or theobromine (Craig and Nguyen, 1984). The pods have antioxidant, analgesic, antiparasitic and anti-diarrheal proprieties (Makris and Kefalas, 2004; Ben Ayache et al., 2020; Min and Hart, 2003; Serairi-Béji et al., 2000). In general, they are very beneficial for the treatment of gastro-intestinal disorders (Rtibi et al., 2017). Furthermore, it has been shown that the fruit of the carob tree can prevent dyslipidaemia and short-term memory deficit (Valero-Muñoz et al., 2017; Alzoubi et al., 2018).

Many studies have been carried out in the past two decades aiming at describing the diversity in *C. siliqua*, using morphometric (Russo and D'Andrea, 2002; Barracosa et al., 2007; Sidina et al., 2009), enzymatic (Batlle et al., 1996; Makrem et al., 2006), chemical (Ayaz et al., 2007; Khlifa et al., 2013; Tetik et al., 2011), cytological (Bureš et al., 2004) and molecular markers (Caruso et al., 2008; Konate et al., 2009; La Malfa et al., 2014; Viruel et al., 2018). In Algeria, there have been very few studies on the diversity of the carob tree. There have been studies on seed diversity for western populations

(Zemouri et al., 2020), on wild carob tree populations (Kocherane et al., 2019), and on morphological and chemical diversity of randomly sampled populations (Boublenza et al., 2019).

There is currently substantial interest in cultivation of the carob tree in Algeria because there is increasing demand for it in the agri-food industry, almost doubling the price of carob on the market (1260€ per ton) and making it more profitable than the olive tree (380€ per ton), which was not previously the case when carob trees were replaced with olive groves (Mahdad and Gaouar, 2016). The interest in this crop, particularly among farmers, requires support essentially in the selection of cultivars to be planted in different regions with different climatic conditions. For example, the Spanish cultivar 'Duraio' was selected for planting new orchards in NE Spain (Tous et al., 2009). Unfortunately, unlike in many Mediterranean countries (Tous et al., 2013), there is no information about Algerian carob cultivars, with the majority of them dating from the colonial period for which there is no archive material. This study is the first in Algeria to attempt, by means of a field prospection and the use of morphometric and statistical tools, to determine potential cultivars of the carob tree in order to improve and sustainably develop carob growing.

Materials and methods

Field prospection

The field prospection was carried out on 33 sites in 26 departments (Figure 1) aiming at establishing a primary inventory based on the available information regarding the situation of carob cultivars in Algeria. Most people surveyed were carob collectors with more than 25 years' experience in carob harvests.

Plant material

In this study, sixty-six accessions were sampled from 19 sites throughout Algeria (Figure 1). The sampled trees (Table 1) covered a wide geographical area (15 regions) from four bioclimatic regions (arid, semi-arid, humid and semi-humid; Roumieux (2012)). For each accession, five leaves were randomly sampled in June 2020 and were characterised using two qualitative (colour and shape) and four quantitative (rachis length, number of leaflets/leaves, leaflet area and leaflet length/width) traits. Thirty pods and three seeds per pod for each tree (harvested from August to September 2020) were randomly collected and twelve morphometric traits were measured (pod length, pod width, pod thickness, pod weight, pulp weight, percentage of pulp, seed length, seed width, seed thickness, seed weight per pod, number of seeds and percentage of seeds). The selection of continuous characters for morphological characterisation was undertaken using a basic list of descriptors for carob tree cultivars (Tous et al., 2013).

Statistical analysis

Morphological data for quantitative traits were analysed by one-way analysis of variance (ANOVA) test using GenStat Discovery Edition 3 software, with Duncan's pairwise comparison between means at a level of significance $\alpha = 0.05$.

In order to examine variations between different sets of quantitative and qualitative parameters, a range of multivariate tools was used, including principal component analysis (PCA), a technique that uses covariances and correlations to identify relationships between quantitative variables, and multiple correspondence analysis (MCA) to analyse the relationship between the qualitative variables of leaves. All quantitative leaf variables were transformed for the MCA analysis into qualitative variables represented by three modalities according to classes created from the following quartiles: <25%, [25% - 75%], >75%.

Hierarchical classification (HC) was performed according to the “ward.D2” agglomerative hierarchical clustering method, which is based on the Euclidean distance. Two indices “Dunn” and “DB” (Dunn, 1974; Davies and Bouldin, 1979) were used via the ″NbClust″ package in R to determine the best number of clusters. Additionally, a heatmap was created as a way of visualising the performance of each accession and hierarchical clustering to identify variables that appear to be characteristic of each cluster.

Analyses were performed with the RStudio program (v. 1.3.1093), using the packages “FactoMineR” for multidimensional exploratory data analysis and “Factoextra” for elegant visualisation of the results of analyses. The functions used for each multivariable analysis were “princomp” for PCA, “hclust” for clustering, “MCA” for multiple correspondence analysis and “heatmap” for heatmap plotting.

The coefficient correlation between the morphological parameters of pods and seeds was analysed using PAST 4.03 software (Hammer et al., 2001) and Bonferroni’s correction as a multiple-comparison correction. Finally, linear discriminant analysis (LDA) as implemented in PAST 4.03 software was used to separate and classify accessions according to their morphological characteristics and regions, and the Jackknife method was used for bias correction.

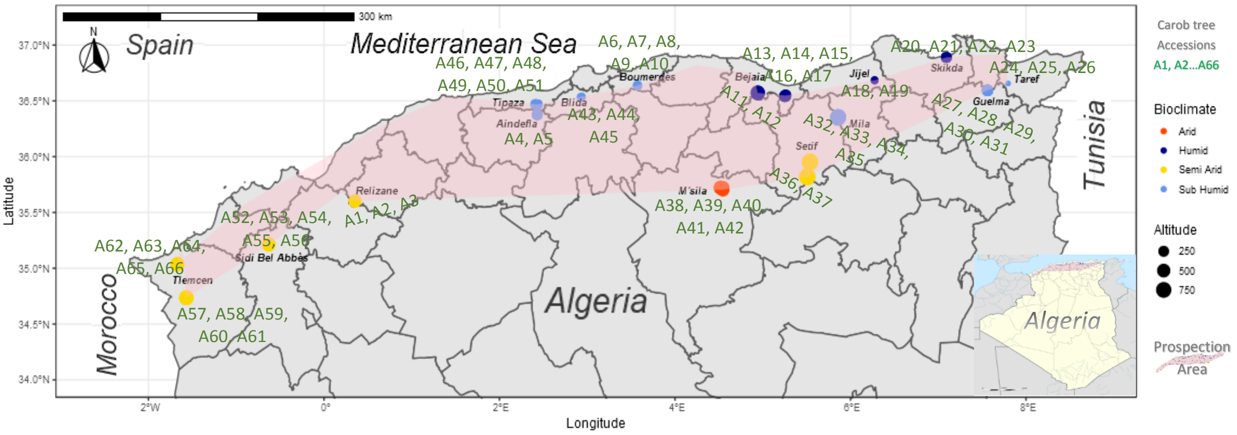

Figure 1. Distribution map of sixty-six carob tree accessions sampled in 19 localities with different bioclimatic stages of northern Algeria.

Results

Field prospection

The prospection conducted throughout Algeria revealed that among the 33 sites visited, 21 were areas of reforestation, 03 were avenue of trees and 07 sites used carob as ornamental species. Only two sites (Blida and Tipaza) could be considered carob orchards (i.e., having more than 100 trees). In 33 sites, just two recognized cultivars were identified: ‘Tlemsani’ (accession A43) referring to the region of Tlemcen, and ‘Maricani’ (accessions A47 and A49), which means “American” (Figure 2).

In all the sites visited, the carob trees resulting from propagation by grafting are referred as “'Hor” or “'Hora” (feminine name) which means “pure”, while trees dispersed by seed propagation are named according to their region. Local names used are “Akajout”, “Akachkach”, “Adjout”, “Berhoucha”, “Belhoucha” and “Hartani”, all these names mean “wild”. Furthermore, two hermaphrodite accessions (A25 and A26) were sampled, and were named as ‘Tarfi’ in reference to the region El Taref.

Additionally, this prospection revealed that *C. siliqua* species is in common association with Olive tree (*Olea europaea*), mastic tree (*Pistacia lentiscus*), and occasionally associated with wild olive tree (*Olea* *oleaster*) and Mount Atlas mastic tree (*Pistacia atlantica*), and rarely with oleander (*Nerium oleander*) in the thalwegs of Algerian steppe.

Table 1. Geographic location and bioclimate of the studied carob tree accessions.

Accession	Region	Latitude	Longitude	Altitude (m)	Bioclimate
A01	Relizane	35°36′09″N	0°21′14″E	397	Semi Arid
A02	Relizane	35°36′09″N	0°21′14″E	397	Semi Arid
A03	Relizane	35°36′08″N	0°21′14″E	399	Semi Arid
A04	Aindefla	36°22′35″N	2°25′51″E	262	Sub Humid
A05	Aindefla	36°22′38″N	2°25′50″E	269	Sub Humid
A06	Boumerdes	36°38′02″N	3°34′47″E	92	Sub Humid
A07	Boumerdes	36°38′16″N	3°34′25″E	130	Sub Humid
A08	Boumerdes	36°38′18″N	3°34′23″E	152	Sub Humid
A09	Boumerdes	36°38′17″N	3°34′21″E	143	Sub Humid
A10	Boumerdes	36°38'04″N	3°34′51″E	70	Sub Humid
A11	Bejaia	36°34′19″N	4°56′35″E	603	Humid
A12	Bejaia	36°34′19″N	4°56′37″E	607	Humid
A13	Bejaia	36°32′54″N	5°15′39″E	289	Humid
A14	Bejaia	36°32′55″N	5°15′39″E	298	Humid
A15	Bejaia	36°32′33″N	5°15′07″E	303	Humid
A16	Bejaia	36°32′32″N	5°15′08″E	285	Humid
A17	Bejaia	36°32′41″N	5°15′24″E	307	Humid
A18	Jijel	36°41′04″N	6°16′28″E	74	Humid
A19	Jijel	36°41′05″N	6°16′31″E	84	Humid
A20	Skikda	36°53′24″N	7°05′32″E	236	Humid
A21	Skikda	36°53′24″N	7°05′33″E	241	Humid
A22	Skikda	36°53′23″N	7°05′29″E	231	Humid
A23	Skikda	36°53′22″N	7°05′33″E	233	Humid
A24	El Taref	36°39′22″N	7°47′44″E	31	Sub Humid
A25*	El Taref	36°39′22″N	7°47′45″E	31	Sub Humid
A26*	El Taref	36°39′22″N	7°47′44″E	31	Sub Humid
A27	Guelma	36°35′39″N	7°33′42″E	284	Sub Humid
A28	Guelma	36°35′39″N	7°33′43″E	278	Sub Humid
A29	Guelma	36°35′40″N	7°33′41″E	286	Sub Humid
A30	Guelma	36°35′40″N	7°33′40″E	291	Sub Humid
A31	Guelma	36°35′40″N	7°33′40″E	291	Sub Humid
A32	Mila	36°21′16″N	5°51′38″E	753	Sub Humid
A33	Mila	36°21′16″N	5°51′38″E	753	Sub Humid
A34	Mila	36°21′14″N	5°51′38″E	763	Sub Humid
A35	Mila	36°21′00″N	5°51′18″E	827	Sub Humid
A36	Setif	35°49′13″N	5°30′26″E	955	Semi Arid
A37	Setif	35°57′08″N	5°32′15″E	940	Semi Arid
A38	M’sila	35°43′21″N	4°31′07″E	490	Arid
A39	M’sila	35°43′21″N	4°31′07″E	490	Arid
A40	M’sila	35°43′22″N	4°31′07″E	490	Arid
A41	M’sila	35°42′16″N	4°32′46″E	477	Arid
A42	M’sila	35°43′16″N	4°32′46″E	488	Arid
A43	Blida	36°31′53″N	2°55′46″E	114	Sub Humid
A44	Blida	36°31′53″N	2°55′48″E	113	Sub Humid
A45	Blida	36°32′15″N	2°56′14″E	97	Sub Humid
A46	Tipaza	36°28′05″N	2°26′10″E	186	Sub Humid
A47	Tipaza	36°28′03″N	2°26′08″E	188	Sub Humid
A48	Tipaza	36°28′01″N	2°26′05″E	192	Sub Humid
A49	Tipaza	36°28′03″N	2°24′40″E	218	Sub Humid
A50	Tipaza	36°28′04″N	2°24′43″E	216	Sub Humid
A51	Tipaza	36°28′04″N	2°24′41″E	217	Sub Humid
A52	Sidi Bel Abbès	35°12′50″N	0°37′47″W	472	Semi Arid
A53	Sidi Bel Abbès	35°12′50″N	0°37′44″W	471	Semi Arid
A54	Sidi Bel Abbès	35°12′50″N	0°37′44″W	471	Semi Arid

A55	Sidi Bel Abbès	35°12′43″N	0°37′47″W	473	Semi Arid
A56	Sidi Bel Abbès	35°12′38″N	0°37′48″W	470	Semi Arid
A57	Tlemcen	34°44′13″N	1°34′07″W	617	Semi Arid
A58	Tlemcen	34°44′12″N	1°34′10″W	619	Semi Arid
A59	Tlemcen	34°44′05″N	1°34′08″W	567	Semi Arid
A60	Tlemcen	34°44′05″N	1°34′08″W	567	Semi Arid
A61	Tlemcen	34°44′05″N	1°34′08″W	567	Semi Arid
A62	Tlemcen	35°02′10″N	1°40′17″W	503	Semi Arid
A63	Tlemcen	35°02′11″N	1°40′18″W	497	Semi Arid
A64	Tlemcen	35°02′09″N	1°40′18″W	513	Semi Arid
A65	Tlemcen	35°02′07″N	1°40′17″W	524	Semi Arid
A66	Tlemcen	35°02′09″N	1°40′17″W	510	Semi Arid

* Hermaphroditic cultivar.

Figure 2. Pods and seeds variability of some Algerian carobs accessions.

Morphometric analysis

ANOVA analysis showed highly significant differences (P<0.001) between accessions for all quantitative traits (Table 2). Leaf dimension traits (rachis length, leaflet area and length/width ratio) of all carob accessions (Table S1) ranged from 9.04 (A24) to 22.16 cm (A14), 11.49 cm^2 (A34) to 33.93 cm^2 (A14), and 1.23 (A61) to 1.73 (A62) respectively. The rachis and leaflets showed on average 13.70 cm length and 19.68 cm^2 area, and the length/width ratio was 1.50 on average. The number of leaflets per leaf were 8.32 on average and varied from 6.0 (A58) to 11.2 (A26 'Tarfi').

The pod dimensions (Table S2) (length and width) ranged from 11.20 cm (A34) to 19.36 cm (A60) and from 1.54 cm (A44) to 3.07 cm (A01), respectively. Both traits presented means of 15.05 cm and 2.13 cm respectively. Pod thickness was thin, of 0.63 cm on average, and ranged from 0.29 cm (A61) to 0.97 cm (A47 ‘Maricani’). Seed dimensions (Table S3) (length, width and thickness) varied from 0.81 cm (A24) to 1.10 cm (A45), 0.59 cm (A08) to 0.81 cm (A01) and 0.23 cm (A25 ‘Tarfi’) to 0.50 cm (A18 and A49 ‘Maricani’) respectively. These seed characteristics were 0.93 cm, 0.71 cm and 0.41 cm on average, respectively.

The weight of the pods varied between 5.8 g (A18) and 27.4 g (A11), with a mean value of 15.17 g. The number of seeds varied from 6.43 (A34) to 13.97 (A19), and a mean value of 10.97. The hermaphroditic accessions A25 and A26 recorded the highest weight (25.03 g) and pulp percentage (93.80 %) respectively. Finally, seed yield ranged from 6.20 % (A26 ‘Tarfi’) to 28.63 % (A18).

Table 2. Extreme values, mean and statistical significance of 16 morphological traits of 66 Algerian carob accessions.

Morphological traits	Min ± SE	Max ± SE	Mean ± SE	CV%	*p-value****
Rachis length (cm)	9.04 ± 1.27	22.16 ± 1.30	13.70 ± 0.37	21.85	< 0.001
Number of leaflets	6.0 ± 0.00	11.2 ± 0.49	8.32 ± 0.14	13.74	< 0.001
Leaflet area (cm^2)	11.49 ± 0.47	33.93 ± 2.67	19.68 ± 0.59	24.41	< 0.001
Length / Width of leaflet	1.23 ± 0.04	1.73 ± 0.08	1.50 ± 0.02	8.41	< 0.001
Pod length (cm)	11.20 ± 0.30	19.36 ± 0.35	15.05 ± 0.25	13.41	< 0.001
Pod width (cm)	1.54 ± 0.04	3.07 ± 0.03	2.13 ± 0.04	15.85	< 0.001
Pod thickness (cm)	0.29 ± 0.02	0.97 ± 0.02	0.63 ± 0.02	27.56	< 0.001
Pod weight (g)	5.8 ± 0.21	27.4 ± 0.55	15.17 ± 0.67	35.65	< 0.001
Pulp weight (g)	4.17 ± 0.19	25.03 ± 1.17	13.16 ± 0.65	39.87	< 0.001
% of pulp	71.37 ± 1.59	93.80 ± 0.24	85.18 ± 0.65	6.16	< 0.001
Number of seeds	6.43 ± 0.42	13.97 ± 0.45	10.97 ± 0.17	12.49	< 0.001
Seed yield (%)	6.20 ± 0.24	28.63 ± 1.59	14.82 ± 0.65	35.44	< 0.001
Seed length (cm)	0.81 ± 0.01	1.10 ± 0.01	0.93 ± 0.01	7.78	< 0.001
Seed width (cm)	0.59 ± 0.01	0.81 ± 0.00	0.71 ± 0.01	6.32	< 0.001
Seed thickness (cm)	0.23 ± 0.01	0.50 ± 0.00	0.41 ± 0.01	11.35	< 0.001
Seed Weight / pod (g)	1.03 ± 0.08	2.71 ± 0.07	2.00 ± 0.04	17.20	< 0.001

Min: Minimum; Max: Maximum; SE: standard error; CV%: coefficient of variation; *** A highly significant *p-value* for all variables studied.

Correlation analysis

The correlation between the 12 analysed morphological traits (pods and seeds) is summarised in Figure 3. The results revealed a correlation between all the characters, except the trait of seed width and number of seeds, percentage of pulp, yield (% of seeds) and seed thickness. Pulp weight had a strongly positive correlation with pod length, pod width and pod thickness, with respective correlation coefficients of r = 0.63, 0.75, 0.64, but a weakly positive correlation with seed number (r = 0.27), seed length (r = 0.38), seed width (r = 0.28) and seed weight (r = 0.31). Furthermore, pulp weight was negatively correlated with yield (r = - 0.63) and seed thickness (r = - 0.31). Yield (% of seeds) was negatively correlated with the majority of traits, pod length, pod width, pod thickness, pod weight and seed length with respective correlation coefficients of r = - 0.16, - 0.51, - 0.44, - 0.55 and - 0.14, while it was positively correlated with seed number (r = 0.28), seed thickness (r = 0.27) and seed weight (r = 0.40).

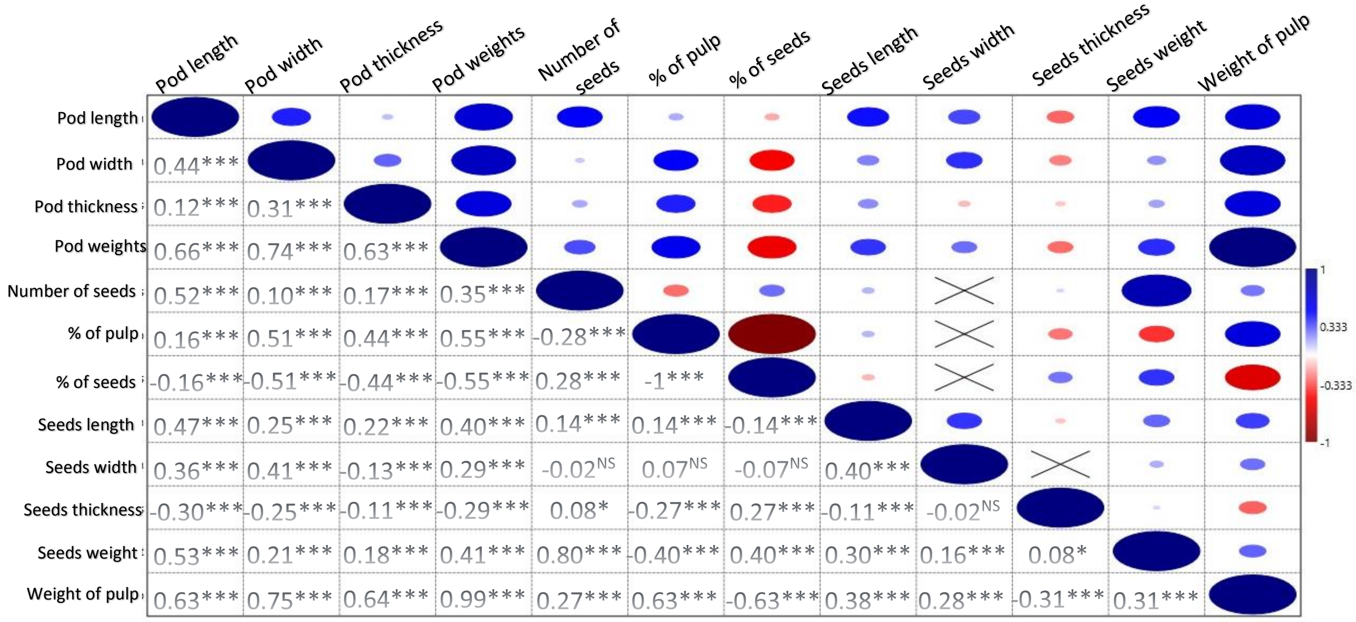

Figure 3. Coefficient correlation between morphological pods and seeds parameters of 66 Algerian carobs accessions (Significant level: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. ns: statistically non-significant).

Multivariate analysis

The multiple correspondence analysis (MCA) for variables regarding leaves is illustrated in Figure 4. The two dimensions of MCA explained 30.22 % of the total of variance over 18 modalities. The MCA provide an opportunity to group the leaves of carob trees into three distinct classes: i) leaves with a short rachis, low number of leaflets, small leaflets, lobed, narrow and green leaves; ii) leaves with a medium rachis, medium number of leaflets, medium leaflets, oval, short and light green leaves, and iii) leaves with a long rachis, large number of leaflets, large leaflets, elliptic, long and dark green leaves.

Principal component analysis of the 12 pod and seed morphological characters is shown in Figure 5. The two first principal components explained 67.5 % of the total variance, the first axis explained 49.6 %, and 17.9 % in the second. The best-represented variables in the first component were pod weight (Cos2 = 0.96), pulp weight (Cos2 = 0.95), yield (Cos2 = 0.73), percentage of pulp (Cos2 = 0.73), pod width (Cos2 = 0.7) and pod length (Cos2 = 0.52). In the second component, seed weight, seed number and seed length were the most significant variables, with a quality of representation of Cos2 = 0.56, 0.37 and 0.24, respectively. The PCA shows a negative correlation between most of pod traits and seed yield, and a null correlation between the latter trait and the other characters of the seed. The latter result seems to be in contradiction with those of correlation analysis between variables, however this ambiguity can be explained by the loss of information recorded by the PCA, which is 32.5 %.

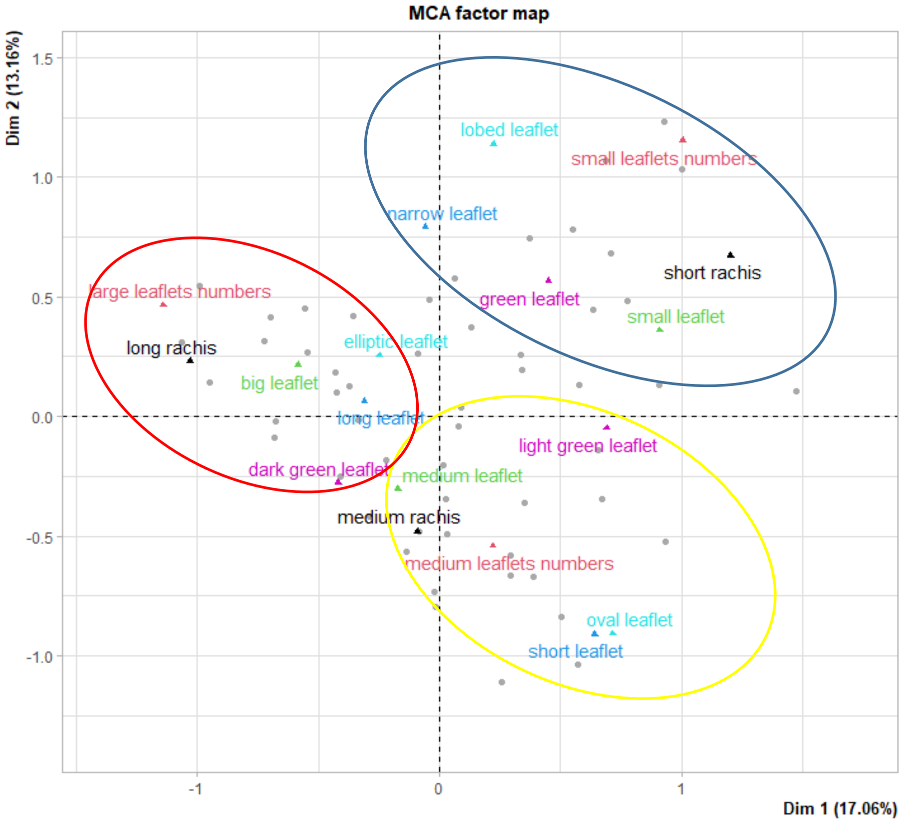

Figure 4. Multiple correspondence analysis of six variables of leaves belonging 66 Algerian carobs accessions. The MCA groups the leaves of carob tree into three distinct classes.

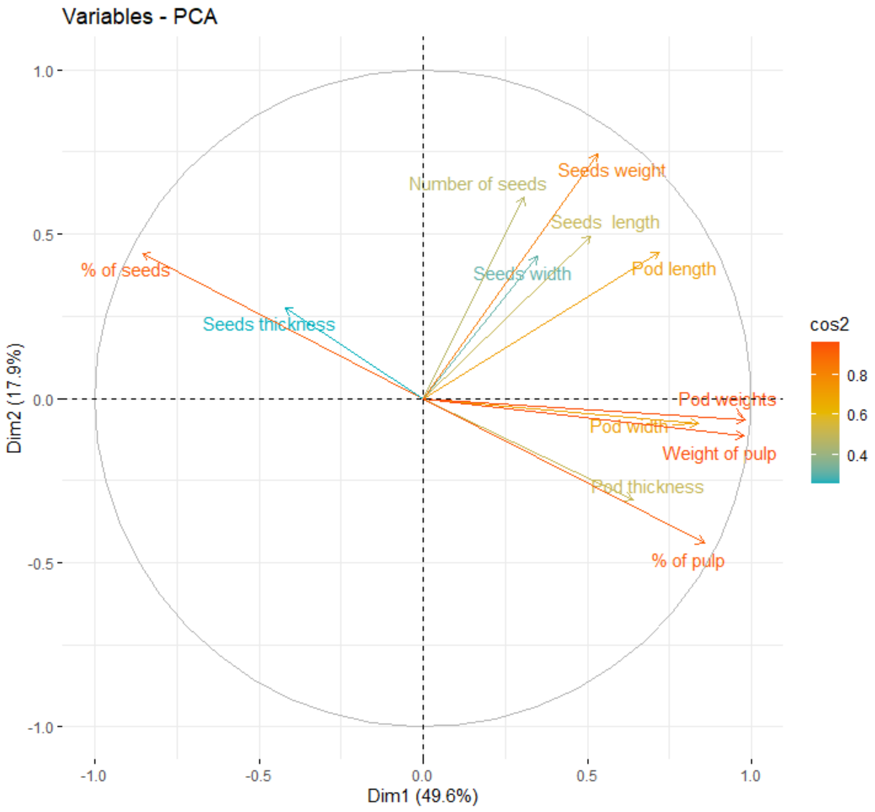

Figure 5. Principal component analysis of 12 morphological traits (pods and seeds) of 66 Algerian carobs accessions.

Hierarchical classification of the different accessions according to their morphometric measurements is presented in Figure 6. The best number of clusters determined by both "Dunn" and "DB" indices was seven. The group that stood out was the one with hermaphrodite accessions (A25 and A26 'Tarfi'). Cluster VII combined three accessions: A32 and A34 located in the east of the country in a sub-humid bioclimatic stage, and A61 located in the far west in a semi-arid bioclimatic stage. The sixth group included four accessions, two from the west (A57 and A58) with a semi-arid bioclimate, one in the centre of the country (A44) with a sub-humid bioclimate, and the last located in the east (A18) with a humid bioclimate. Cluster IV combined the cultivar Maricani (A47 and A49) with accessions from the region of Boumerdes (A06, A08 and A09), while the cultivar Tlemsani (A43) was very close to the accession (A04) in the third cluster. In the first cluster, all the accessions (A02, A03 and A01) from the region of Relizane and most accessions (A27, A28 and A31) from the region of Guelma were grouped together. Finally, cluster V combined the greatest number of accessions, which were located throughout the country and in all types of bioclimatic stages.

The heatmap (Figure 7) shows that Cluster I was characterised by accessions with a high percentage of pulp and a low yield of seed. Cluster II, which grouped together the two hermaphrodite accessions, was characterised by a low percentage of seeds and thin seeds, and also by high pulp weight. Cluster III was characterised by a high weight of pulp and seed, and high number of seed, while a thick pod and narrow seeds distinguished Cluster IV. Cluster V, which grouped together most accessions, was characterised by a medium to high seed yield and a medium to low percentage of pulp. Cluster VI was distinguished by several traits such as a high percentage of seeds, low percentage of pulp and short pods with a small weight. Finally, Cluster VII contained accessions with a small number of short seeds and low pod and seed weight.

Linear discriminant analysis (LDA) for the classification of accessions per region is shown in Figure 8. LDA identified two linear discriminants that explained 57.37 % of the total variance and clearly showed three separate accession groups belonging to three different regions: El Taref, Relizane and Guelma. LDA indicated that 69.7 % of accessions were correctly classified according to their origin, but only 39.39 % with the correction of Jackknife method, which represents 26 accessions out of a total of 66 accessions studied. These 26 accessions were originally from 11 regions: Relizane (A01, A02 and A03), Boumerdes (A06, A08 and A09), Bejaia (A16 and A17), Skikda (A21 and A22), El Taref (A25 and A26, 'Tarfi'), Guelma (A27, A28, A29 and A31), Mila (A32 and A35), M'sila (A40 and A42), Tipaza (A47 and A49, 'Maricani'), Sidi Bel Abbès (A54) and Tlemcen (A59, A63 and A65).

Discussion

Our study demonstrates the enormous morphological variability of carob accessions across Algeria, with traits that overlap with carob trees to other countries of the Mediterranean basin (Table 3 and 4). Especially for the pod parameters; such as Cypriot pods with a mean length of 15.24 cm (Kyratzis et al., 2021), Spanish pods with a mean width of 2.11 cm (Albanell et al., 1996), and Moroccan pods with a mean thickness at 0.64 cm (El Kahkahi et al., 2014). Similar results were found for seed dimensions very close to Spanish seed cultivars, presenting extreme values passed from 0.75 to 1.10 cm and 0.59 to 0.80 cm, respectively (Albanell et al., 1996). However, the Algerian carob germplasm presents the most range variation of seed thickness compared to the Mediterranean populations, with a coefficient of variation (11.35 %). This probably indicates that, for this trait, genetic diversity within Algerian cultivars is high. Its mean was 0.41 cm, coinciding with those observed among Tunisian populations and Syrian accessions (Naghmouchi et al., 2009; Mahfoud et al., 2018).

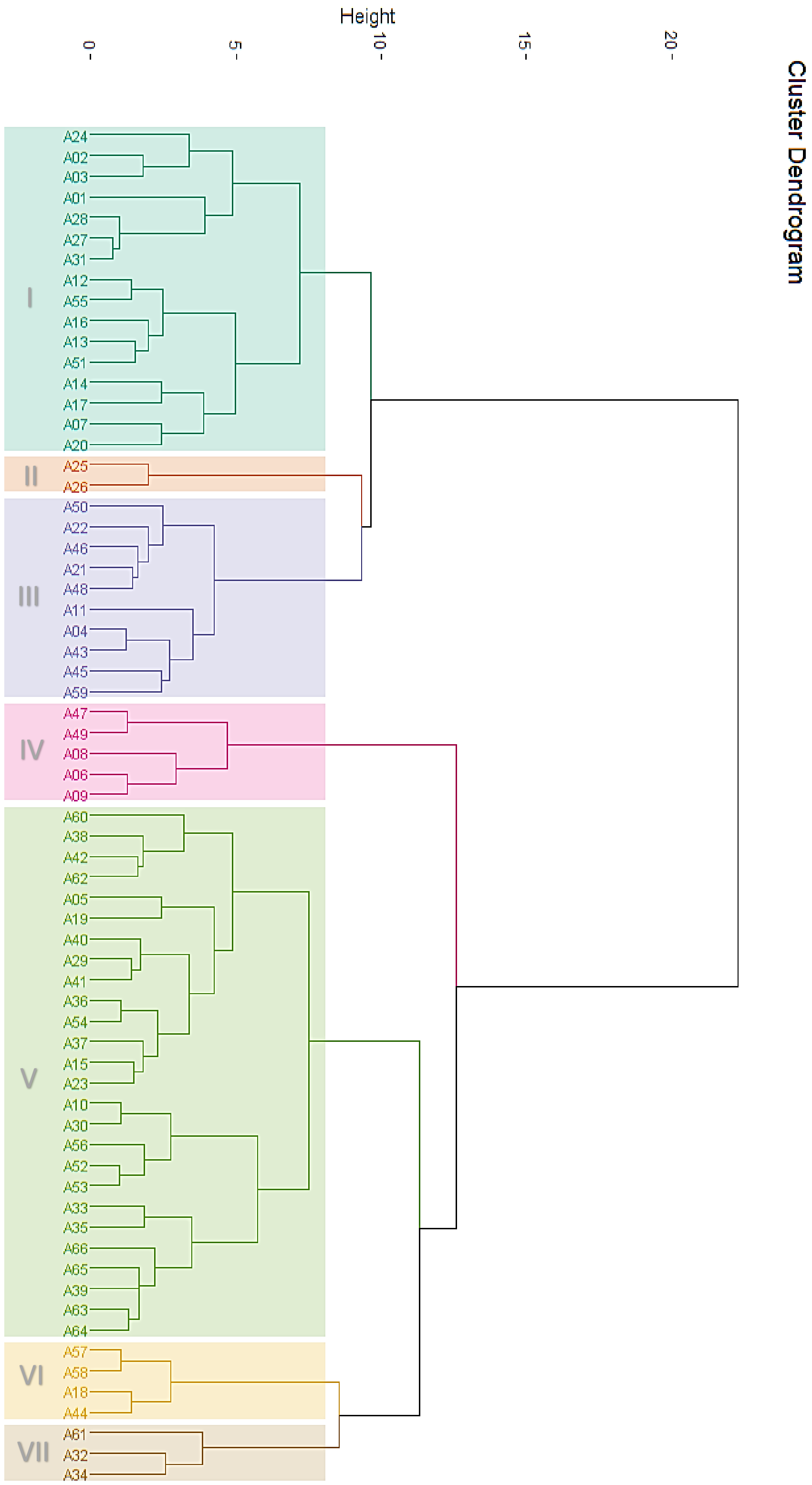

Figure 6. Hierarchical classification of 66 Algerian carobs accessions based on their 12 morphological characters of pods and seeds.

The weight of the Algerian pods overlaps with those observed by Albanell et al. (1996), who obtained a range from 5.09 g to 29.84 g, with an average weight of 14.88 g in Spanish pods. The number of Algerian seeds was close to the average recorded among Lebanese accessions (10.93) (Chami et al., 2018). Finally, the seed yield from these Algerian accessions, with a mean of 14.88 %, could be considered satisfactory compared with the seed yield recorded from other carobs in the Mediterranean basin. In conclusion, it appears from this comparison that the most similar carob pods in the Mediterranean basin to those in Algeria are Spanish carob pods.

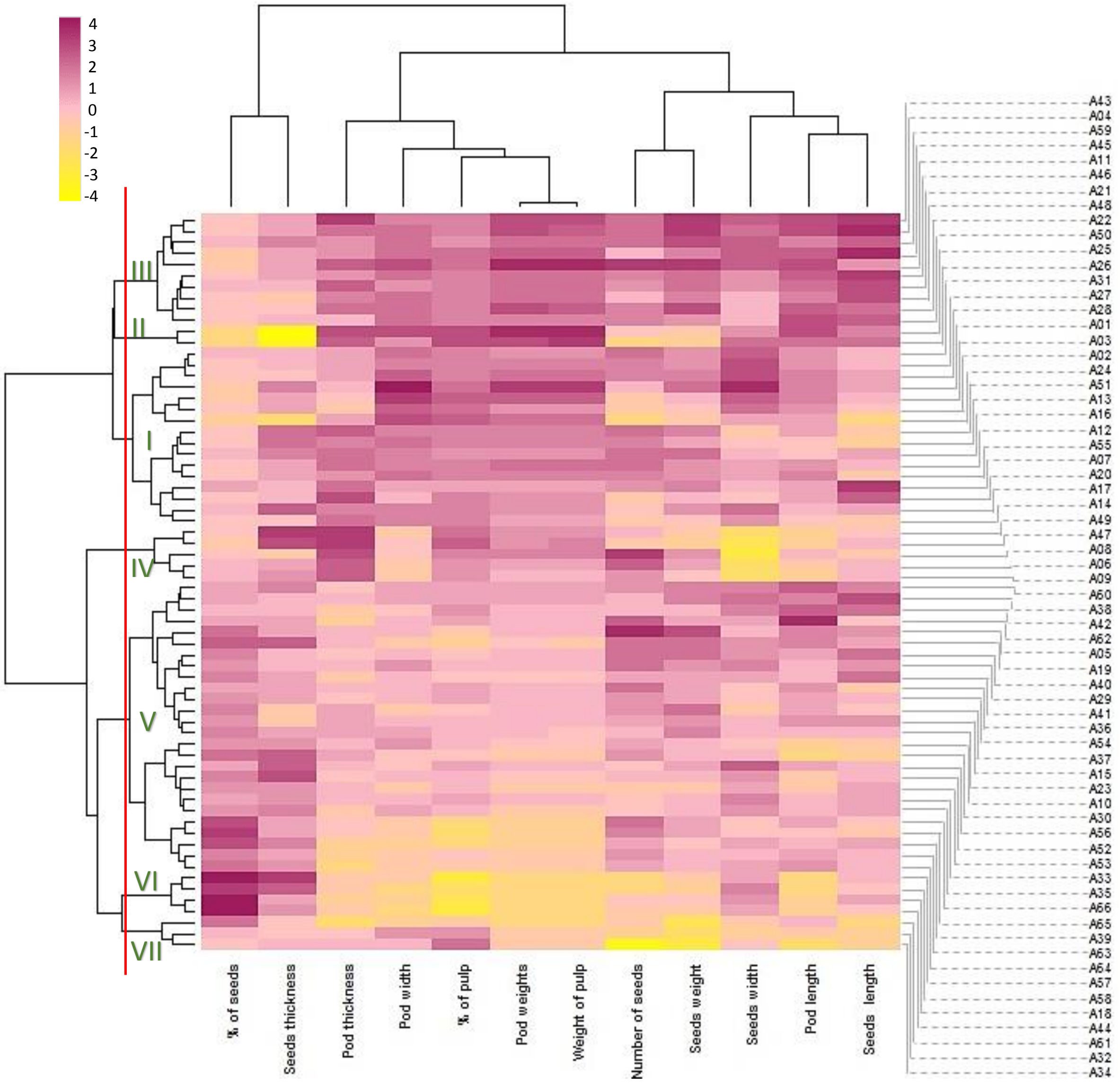

Figure 7. Heatmap of morphological performance of 66 Algerian carobs accessions.

The number of leaflets per leaf (mean = 8.32) was significantly higher than those recorded by Chami et al. (2018) for Lebanon accessions (mean = 7.88), by El Bakkali et al. (2019) for Moroccan populations (mean = 7.2) and by Korkmaz et al. (2020) for Turkish wild trees (mean = 6.43).

According to Albanell et al. (1996), to improve the yield of seed and gum it is possible to select a light, thin, narrow carob pod with a high number of thick, short seeds. The characteristics of pod length and seed width were not important since these were not correlated with seed yield. These conclusions were confirmed by our results of the analysis of morphometric parameters and their correlations. For a high pulp weight, a heavy, long, wide, thick pod should be selected with a high number of long, wide, thin seeds.

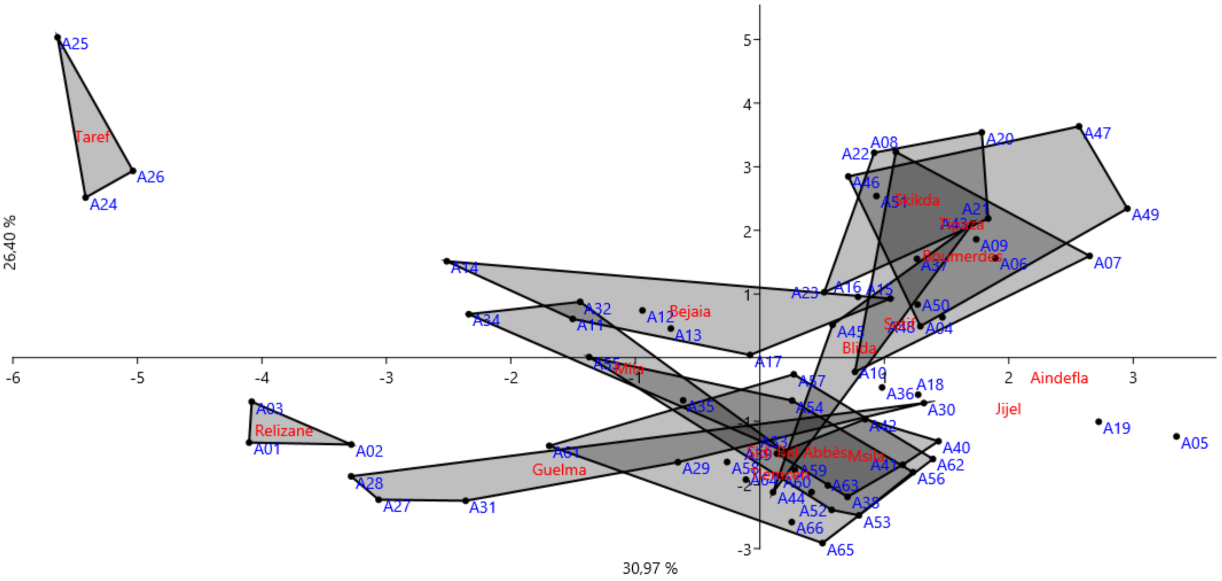

Figure 8. Linear discriminant Analysis of 66 Algerian carobs accessions.

Principal component analysis showed two groups of variables, one represents pod characters, while the other represents seed traits. According to the same multivariate analysis, a high pulp weight leads to lower seed yield, which is similar to the results of Boublenza et al. (2019).

Hierarchical clustering analysis revealed significant genetic diversity among the Algerian carob accessions studied. It also showed that the distribution of these accessions was not influenced by type of bioclimate. This suggests that morphometric traits are probably controlled more by genes than by bioclimate; indeed, the results of a study conducted by Kyratzis et al. (2021) suggest the same hypothesis.

It appears from the results of linear discriminant analysis and hierarchical classification and the performance of morphological traits of each accession for each cluster (Heatmap analysis) that among the sixty-six accessions studied, eleven are potential cultivars. Two cultivars are already known and confirmed by this study – ‘Tlemsani’ (A43) and ‘Maricani’ (A47; A49) – and nine other cultivars were identified in the present study: the hermaphroditic cultivar Tarfi (A25; A26) which could be used for pollination in the field and the female cultivars which were given the following names: ‘Relizani’ (A01; A02; A03), ‘Bumerdas’ (A08), ‘Bejaoui’ (A11), ‘Skikdi’ (A21; A22), ‘Guelmi’ (A27; A28; A31), ‘Msili’ (A42), ‘Abassi’ (A54) and ‘Zayanid’ (A59). These cultivars could be used as germplasms for reforestation programmes and for the establishment of high-yielding Algerian carob orchards.

Table 3. Comparison of morphological characteristics of carob pods from Mediterranean countries.

Morphological traits of pod		Algerian(1) accessions (N=66)	Spanish(2) cultivars (N=182)	Italian(3) cultivars (N=54)	Portuguese(4) cultivars (N=15)	Turkish(5) genotypes (N=32)	Moroccan(6) accessions (N=47)	Syrian(7) accessions (N=24)	Lebanese(8) accessions (N=59)	Cypriot(9) accessions (N=124)
Length (cm)	Mini	11.20	7.71	13.30	12.95	14.25	10.11	12.87	10.83	7.34*
Short (<14) **	Max	19.36	27.28	21.10	20.36	19.08	16.63	22.32	23.42	20.20*
Medium (14-18)	Mean	15.05	15.83	17.10	17.07*	16.91	13.85	17.46*	16.19	15.24*
Long (>18)	CV%	13.41	n.m	7.70	12.33*	7.00	10.81*	13.08*	21.26	15.41*
Width (cm)	Mini	1.54	1.44	1.50	1.62	1.98	1.21	1.98	1.43	1.62*
Small (<1.85) **	Max	3.07	2.68	2.67	2.34	2.35	1.81	3.12	2.70	2.71*
Medium (1.85-2.25)	Mean	2.13	2.11	2.30	2.05*	2.18	1.57	2.47*	2.21	2.32*
Big (>2.25)	CV%	15.85	n.m	5.80	8.36*	5.00	11.23*	11.36*	14.64	8.53*
Thickness (cm)	Mini	0.29	0.54	0.50	0.72	0.52	0.45	0.58	0.46	0.59*
Thin (<0.75) **	Max	0.97	1.32	1.33	1.10	1.12	0.87	1.26	1.22	1.28*
Medium (0.75-0.95)	Mean	0.63	0.85	0.96	0.98*	0.88	0.64	0.89*	0.83	1.00*
Thick (>0.95)	CV%	27.56	n.m	9.20	13.05*	14.00	13.45*	20.91*	19.13	13.49*
Weight (g)	Mini	5.8	5.09	n.m	11.46	14.34*	n.m	8.99	5.90	5.29*
Small (<12) **	Max	27.4	29.84	n.m	26.39	29.58*	n.m	26.33	37.65	30.46*
Medium (12-17)	Mean	15.17	14.88	n.m	18.67*	21.52*	n.m	16.42*	20.34	17.35*
High (>17)	CV%	35.65	n.m	n.m	19.13*	3.80*	n.m	29.76*	39.33	29.13*
Pulp weight (g)	Mini	4.17	3.74	n.m	n.m	12.37*	3.41	n.m	4.49	n.m
	Max	25.03	27.43	n.m	n.m	27.24*	7.42	n.m	34.67	n.m
	Mean	13.16	13.00	n.m	n.m	19.70*	5.96*	n.m	18.00	n.m
	CV%	39.87	n.m	n.m	n.m	4.00*	17.04*	n.m	42.94	n.m
N° of seeds	Mini	6.43	2.88	n.m	10.15	7.67*	8.43	8.26	7.86	n.m
Few (<8.5) **	Max	13.97	14.76	n.m	13.69	12.3*	15.53	16.11	14.30	n.m
Medium (8.5-10.5)	Mean	10.97	10.00	n.m	12.17*	10.45*	12.26	11.81*	10.93	n.m
Many (>10.5)	CV%	12.49	n.m	n.m	9.56*	2.40*	11.73*	17.94*	13.45	n.m

** Ranks of morphological characters of the carob tree (Tous et al., 2013). * Values calculated from authors data. n.m: not mentioned.

References: (1) Present work; (2) Albanell et al., 1996; (3) Russo and D'Andrea, 2002; (4) Barracosa et al., 2007; (5) Tetik et al., 2011; (6) El Kahkahi et al., 2014; (7) Mahfoud et al., 2018; (8) Chami et al., 2018; (9) Kyratzis et al., 2021.

Table 4. Comparison of morphological characteristics of carob seeds from Mediterranean countries.

Morphological traits of seed		Algerian(1) accessions (N=66)	Spanish(2) cultivars (N=182)	Italian(3) cultivars (N=54)	Portuguese(4) cultivars (N=15)	Tunisian(5) populations (N=19)	Turkish(6) genotypes (N=32)	Moroccan(7) accessions (N=47)	Syrian(8) accessions (N=24)	Lebanese(9) accessions (N=59)
Seed yield (%)	Mini	6.20	3.55	n.m	10.85	8.89	5.17	17.4	n.m	6.7
Low (<10) **	Max	28.63	29.41	n.m	18.14	24.50	14.01	27.83	n.m	36.6
Medium (10-15)	Mean	14.82	12.11	n.m	13.11*	17.20	8.79	23.02*	n.m	13.13
High (>15)	CV%	35.44	n.m	n.m	15.93*	30.06	27.00	10.51*	n.m	44.63
Length (cm)	Mini	0.81	0.75	0.73	0.87	0.80	n.m	0.75	0.81	0.77
Short (<0.85) **	Max	1.10	1.10	1.12	1.02	0.97	n.m	0.92	1.14	1.15
Medium (0.85-0.95)	Mean	0.93	0.96	0.93	0.96*	0.91	n.m	0.82*	0.99*	0.97
Long (>0.95)	CV%	7.78	n.m	4.40	4.40*	5.52	n.m	5.00*	8.62*	8.96
Width (cm)	Mini	0.59	0.59	0.62	0.64	0.65	n.m	0.57	0.62	0.60
Narrow (<0.675) **	Max	0.81	0.80	0.78	0.77	0.74	n.m	0.72	0.83	0.86
Medium (0.67-0.72)	Mean	0.71	0.70	0.68	0.71*	0.69	n.m	0.63*	0.72*	0.74
Wide (>0.72)	CV%	6.32	n.m	4.40	4.92*	4.18	n.m	6.32*	6.60*	9.43
Thickness (cm)	Mini	0.23	0.31	0.32	0.38	0.35	n.m	0.32	0.37	0.37
Thin (<0.38) **	Max	0.50	0.47	0.47	0.52	0.47	n.m	0.45	0.46	0.53
Medium (0.38-0.45)	Mean	0.41	0.38	0.39	0.42*	0.41	n.m	0.40*	0.41*	0.43
Thick (>0.45)	CV%	11.35	n.m	7.20	8.13*	9.81	n.m	7.07*	7.06*	8.67
Weight / pod (g)	Mini	1.03	0.35	n.m	1.84	n.m	1.15*	1.09	n.m	1.36
	Max	2.71	3.13	n.m	2.99	n.m	2.34*	2.62	n.m	3.05
	Mean	2.00	1.88	n.m	2.36*	n.m	1.82*	1.76	n.m	2.24
	CV%	17.20	n.m	n.m	11.79*	n.m	n.m	18.97*	n.m	20.09

** Ranks of morphological characters of the carob tree (Tous et al., 2013). * Values calculated from authors data. n.m: not mentioned.

References: (1) Present work; (2) Albanell et al., 1996; (3) Russo and D'Andrea, 2002; (4) Barracosa et al., 2007; (5) Naghmouchi et al., 2009; (6) Tetik et al., 2011; (7) El Kahkahi et al., 2014; (8) Mahfoud et al., 2018; (9) Chami et al., 2018.

Conclusion

This study compiled the first inventory of Algerian carob cultivars based on field prospection and a selection of morphometric tools and statistical analysis. The findings are intriguing and could serve as a springboard for reforestation efforts and the establishment of efficient and viable carob orchards. However, it is necessary to use dominant and codominant molecular markers (AFLP, SSR, and SNP) to determine the genetic similarities between the Algerian carob accessions. This step is fundamental to selecting the best germplasms according to their agronomic and commercial value.

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Author contributions

Y.M.M. designed the study, carried out the field and laboratory work, performed the statistical analysis, wrote and edited the manuscript. R.M.M. participated in the statistical analysis and contributed to the writing of the manuscript. J.V. revised and contributed to the writing of the manuscript. N.S. carried out the field and laboratory work. S.B.S.G. supervised the study and revised the manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Supplementary table 1. Leaf characteristics of 66 Algerian carob trees accessions.

Acc	Rachis length (cm)*	Number of leaflets*	Leaflet area (cm^2)*	Length / Width of leaflet*	Leaflet shape	Leaflet colour
A01	17.26 ±0.82^{cdef}	10.0 ±0.00^{abc}	27.00 ±1.96^{bcdef}	1.73 ±0.02^{a}	elliptic	dark green
A02	14.80 ±0.82^{efghijklmnopq}	8.8 ±0.49^{bcdefgh}	30.36 ±2.86^{ab}	1.66 ±0.04^{abcde}	elliptic	dark green
A03	11.90 ±0.76^{klmnopqrstuv}	8.6 ±0.40^{bcdefghi}	19.93 ±1.11^{hijklmnopq}	1.70 ±0.02^{abc}	elliptic	dark green
A04	15.22 ±2.37^{defghijklmno}	8.4 ±0.75^{cdefghij}	23.41 ±3.14^{defghijkl}	1.43 ±0.03^{lmnopqrstuvwxyz}	elliptic	dark green
A05	15.12 ±0.49^{defghijklmno}	7.8 ±0.66^{fghijkl}	20.51 ±3.34^{efghijklmnopq}	1.41 ±0.04^{opqrstuvwxyz}	elliptic	dark green
A06	12.46 ±1.21^{hijklmnopqrstuv}	8.2 ±0.66^{defghij}	20.82 ±2.00^{efghijklmnop}	1.34 ±0.05$^{vwxyza'b'}$	elliptic	dark green
A07	14.44 ±0.96^{efghijklmnopqr}	7.0 ±0.63^{ijklm}	25.36 ±1.09^{bcdefgh}	1.38 ±0.05$^{rstuvwxyza'}$	elliptic	green
A08	13.44 ±0.88^{efghijklmnopqrstu}	6.8 ±0.49^{jklm}	25.26 ±2.96^{bcdefghi}	1.46 ±0.03^{hijklmnopqrstuvwx}	elliptic	light green
A09	14.52 ±1.78^{efghijklmnopqr}	7.2 ±0.49^{hijklm}	23.84 ±2.11^{cdefghij}	1.46 ±0.03^{hijklmnopqrstuvwx}	elliptic	green
A10	14.92 ±1.23^{defghijklmnop}	7.8 ±0.49^{fghijkl}	30.19 ±2.03^{abc}	1.63 ±0.04^{abcdef}	elliptic	green
A11	15.60 ±1.45^{defghijklm}	9.6 ±0.40^{abcde}	20.60 ±2.23^{efghijklmnopq}	1.61 ±0.04^{abcdefghij}	elliptic	light green
A12	11.48 ±1.37^{mnopqrstuv}	8.8 ±0.49^{bcdefgh}	12.94 ±0.63^{rstu}	1.42 ±0.04^{nopqrstuvwxyz}	elliptic	dark green
A13	12.20 ±1.74^{jklmnopqrstuv}	7.8 ±0.49^{fghijkl}	17.80 ±1.93^{jklmnopqrstu}	1.48 ±0.07^{fghijklmnopqrstuv}	elliptic	light green
A14	22.16 ±1.30^{a}	9.6 ±0.24^{abcde}	33.93 ±2.67^{a}	1.67 ±0.07^{abcd}	elliptic	dark green
A15	14.78 ±0.97^{efghijklmnopq}	7.8 ±0.49^{fghijkl}	22.02 ±0.16^{defghijklmno}	1.28 ±0.02$^{za'b'}$	oval	green
A16	10.36 ±0.52^{rstuv}	6.4 ±0.51^{klm}	20.31 ±0.74^{efghijklmnopq}	1.55 ±0.03^{cdefghijklmnop}	elliptic	green
A17	16.65 ±1.51^{cdefgh}	9.8 ±0.66^{abcd}	23.23 ±1.16^{defghijkl}	1.57 ±0.03^{bcdefghijklmn}	elliptic	dark green
A18	12.74 ±0.62^{ghijklmnopqrstuv}	9.6 ±0.24^{abcde}	17.54 ±1.55^{jklmnopqrstu}	1.51 ±0.02^{efghijklmnopqrs}	elliptic	dark green
A19	13.52 ±1.88^{efghijklmnopqrstu}	9.0 ±1.00^{bcdefg}	24.68 ±2.53^{bcdefghi}	1.35 ±0.02$^{tuvwxyza'b'}$	oval	green
A20	14.40 ±2.26^{efghijklmnopqr}	7.2 ±0.49^{hijklm}	27.89 ±2.98^{bcd}	1.45 ±0.04^{klmnopqrstuvwx}	elliptic	dark green
A21	17.48 ±0.94^{bcde}	7.6 ±0.40^{ghijklm}	27.00 ±3.28^{bcde}	1.56 ±0.03^{cdefghijklmno}	elliptic	dark green
A22	13.50 ±0.82^{efghijklmnopqrstu}	8.0 ±0.32^{efghijk}	17.87 ±1.39^{jklmnopqrstu}	1.34 ±0.03$^{uvwxyza'b'}$	oval	green
A23	15.68 ±0.72^{defghijklm}	8.6 ±0.24^{bcdefghi}	23.48 ±2.12^{defghijk}	1.47 ±0.06^{ghijklmnopqrstuvw}	elliptic	dark green
A24	9.04 ±1.27^{v}	6.4 ±0.75^{klm}	12.75 ±0.79^{stu}	1.35 ±0.03$^{tuvwxyza'b'}$	oval	light green
A25	21.08 ±1.23^{ab}	10.0 ±0.89^{abc}	21.36 ±2.28^{defghijklmno}	1.43 ±0.06^{mnopqrstuvwxyz}	elliptic	dark green
A26	19.98 ±1.09^{abc}	11.2 ±0.49^{a}	20.83 ±2.71^{efghijklmnop}	1.44 ±0.03^{klmnopqrstuvwxy}	elliptic	dark green
A27	14.02 ±1.62^{efghijklmnopqrs}	7.6 ±0.40^{ghijklm}	19.29 ±2.05^{hijklmnopqrs}	1.62 ±0.07^{abcdefg}	elliptic	dark green
A28	13.30 ±1.38^{efghijklmnopqrstuv}	7.6 ±0.40^{ghijklm}	20.29 ±2.09^{eghijklmnopq}	1.59 ±0.02^{abcdefghijkl}	elliptic	dark green
A29	11.74 ±1.28^{lmnopqrstuv}	8.0 ±0.55^{efghijk}	17.38 ±1.31^{jklmnopqrstu}	1.58 ±0.04^{abcdefghijklm}	elliptic	dark green
A30	16.56 ±1.76^{cdefghi}	8.0 ±0.84^{efghijk}	13.83 ±1.73^{qrstu}	1.36 ±0.04$^{stuvwxyza'b'}$	oval	dark green
A31	12.00 ±0.62^{jklmnopqrstuv}	7.6 ±0.40^{ghijklm}	15.76 ±1.20^{nopqrstu}	1.61 ±0.07^{abcdefghij}	elliptic	dark green
A32	10.42 ±1.63^{rstuv}	8.8 ±0.49^{bcdefgh}	17.10 ±1.93^{jklmnopqrstu}	1.60 ±0.07^{abcdefghijk}	elliptic	dark green
A33	10.62 ±0.48^{qrstuv}	8.0 ±0.00^{efghijk}	13.74 ±1.01^{qrstu}	1.59 ±0.04^{abcdefghijkl}	elliptic	green
A34	9.36 ±0.83^{uv}	7.0 ±0.63^{ijklm}	11.49 ±0.47^{u}	1.61 ±0.04^{abcdefghij}	elliptic	light green
A35	9.36 ±0.72^{uv}	7.6 ±0.40^{ghijklm}	13.91 ±1.48^{qrstu}	1.72 ±0.03^{ab}	elliptic	light green
A36	20.06 ±2.04^{abc}	9.6 ±0.40^{abcde}	22.56 ±1.62^{defghijklmn}	1.50 ±0.03^{fghijklmnopqrst}	elliptic	dark green
A37	9.48 ±0.81^{tuv}	7.6 ±0.24^{ghijklm}	15.83 ±0.89^{nopqrstu}	1.32 ±0.07$^{wxyza'b'}$	oval	dark green
A38	13.22 ±0.75^{efghijklmnopqrstuv}	8.2 ±0.66^{defghij}	13.96 ±1.19^{pqrstu}	1.62 ±0.07^{abcdefgh}	elliptic	dark green
A39	16.16 ±0.74^{cdefghijk}	10.2 ±0.20^{ab}	17.38 ±2.56^{jklmnopqrstu}	1.49 ±0.04^{fghijklmnopqrstu}	elliptic	green
A40	13.58 ±2.81^{efghijklmnopqrstu}	7.6 ±0.68^{ghijklm}	25.12 ±4.48^{bcdefghi}	1.35 ±0.06$^{tuvwxyza'b'}$	elliptic	dark green
A41	13.18 ±0.31^{fghijklmnopqrstuv}	10.0 ±0.00^{abc}	14.07 ±0.51^{pqrstu}	1.44 ±0.04^{klmnopqrstuvwxy}	elliptic	dark green
A42	13.92 ±1.10^{efghijklmnopqrs}	8.2 ±0.66^{defghij}	17.72 ±1.66^{jklmnopqrstu}	1.45 ±0.02^{klmnopqrstuvwx}	oval	dark green
A43	15.34 ±1.49^{defghijklmn}	10.2 ±0.20^{ab}	22.85 ±2.04^{defghijklm}	1.72 ±0.08^{ab}	elliptic	dark green
A44	10.08 ±0.48^{tuv}	7.6 ±0.40^{ghijklm}	15.36 ±0.78^{opqrstu}	1.41 ±0.02^{opqrstuvwxyz}	elliptic	green
A45	11.94 ±1.36^{klmnopqrstuv}	8.6 ±0.60^{bcdefghi}	16.10 ±1.11^{mnopqrstu}	1.49 ±0.04^{fghijklmnopqrstu}	elliptic	dark green
A46	12.34 ±1.28^{ijklmnopqrstuv}	8.6 ±0.60^{bcdefghi}	15.77 ±1.93^{nopqrstu}	1.45 ±0.02^{klmnopqrstuvwx}	oval	dark green
A47	11.56 ±1.33^{mnopqrstuv}	8.2 ±0.37^{defghij}	18.49 ±2.05^{ijklmnopqrst}	1.25 ±0.02$^{a'b'}$	oval	light green
A48	12.06 ±0.70^{jklmnopqrstuv}	8.6 ±0.40^{bcdefghi}	15.85 ±1.61^{nopqrstu}	1.46 ±0.05^{jklmnopqrstuvwx}	elliptic	dark green
A49	12.10 ±0.24^{jklmnopqrstuv}	7.2 ±0.49^{hijklm}	26.95 ±1.52^{bcdefg}	1.43 ±0.03^{mnopqrstuvwxyz}	oval	green
A50	16.86 ±0.85^{cdefg}	9.6 ±0.40^{abcde}	20.82 ±0.99^{efghijklmnop}	1.40 ±0.02^{pqrstuvwxyz}	oval	light green
A51	15.58 ±0.65^{defghijklm}	10.0 ±0.63^{abc}	18.71 ±1.18^{hijklmnopqrst}	1.52 ±0.03^{defghijklmnopqr}	elliptic	dark green
A52	9.10 ±0.51^{v}	6.2 ±0.20^{lm}	17.50 ±2.52^{jklmnopqrstu}	1.55 ±0.06^{defghijklmnopq}	oval	dark green
A53	11.38 ±0.56^{mnopqrstuv}	7.6 ±0.24^{ghijklm}	19.83 ±0.93^{hijklmnopq}	1.29 ±0.03$^{yza'b'}$	elliptic	dark green
A54	11.24 ±1.09^{nopqrstuv}	7.2 ±0.49^{hijklm}	18.60 ±1.52^{hijklmnopqrst}	1.66 ±0.04^{abcde}	elliptic	dark green
A55	16.28 ±0.58^{cdefghij}	10.0 ±0.32^{abc}	15.33 ±0.54^{opqrstu}	1.72 ±0.04^{ab}	oval	green
A56	18.96 ±0.66^{abcd}	9.4 ±0.40^{bcdef}	25.02 ±1.99^{bcdefghi}	1.39 ±0.04$^{qrstuvwxyza'}$	elliptic	green
A57	10.62 ±0.36^{pqrstuv}	8.0 ±0.00^{efghijk}	11.91 ±1.17^{tu}	1.62 ±0.04^{abcdefghi}	elliptic	green
A58	9.04 ±0.42^{v}	6.0 ±0.00^{m}	15.21 ±1.15^{opqrstu}	1.61 ±0.02^{abcdefghi}	elliptic	green
A59	13.88 ±0.85^{efghijklmnopqrs}	9.6 ±0.40^{abcde}	16.72 ±1.88^{klmnopqrstu}	1.54 ±0.03^{defghijklmnopq}	elliptic	green
A60	17.00 ±1.25^{cdefg}	8.4 ±0.24^{cdefghij}	20.27 ±0.99^{ghijklmnopq}	1.43 ±0.04^{mnopqrstuvwxyz}	lobed	dark green
A61	14.16 ±0.48^{efghijklmnopqrs}	8.0 ±0.32^{efghijk}	17.41 ±0.88^{jklmnopqrstu}	1.23 ±0.04$^{b'}$	oval	dark green
A62	13.70 ±1.41^{efghijklmnopqrst}	9.6 ±0.40^{abcde}	16.60 ±1.14^{lmnopqrstu}	1.73 ±0.08^{a}	elliptic	green
A63	10.96 ±1.07^{opqrstuv}	8.2 ±0.49^{defghij}	19.70 ±2.76^{hijklmnopqr}	1.54 ±0.04^{defghijklmnopq}	oval	light green
A64	11.00 ±0.71^{opqrstuv}	7.6 ±0.40^{ghijklm}	15.44 ±0.90^{opqrstu}	1.57 ±0.04^{bcdefghijklmn}	elliptic	green
A65	11.16 ±1.40^{nopqrstuv}	6.4 ±0.51^{klm}	17.44 ±1.42^{jklmnopqrstu}	1.46 ±0.05^{ijklmnopqrstuvwx}	lobed	green
A66	15.92 ±1.62^{defghijkl}	9.0 ±0.45^{bcdefg}	20.61 ±3.42^{efghijklmnopq}	1.60 ±0.01^{abcdefghij}	oval	light green
Mini	9.04	6.0	11.49	1.23		
Max	22.16	11.2	33.93	1.73		
Mean	13.70	8.32	19.68	1.50		
CV%	21.85	13.74	24.41	8.41		

Acc: Accession. Means with different letters in the same column differ significantly ($p < 0.05$). * Significantly different at $P < 0.001$.

Supplementary table 2. Pod characteristics of 66 Algerian carob trees accessions.

Acc	Length (cm)*	Width (cm)*	Thickness (cm)*	Weight of pods (g)*	Weight of pulp (g)*	% of pulp*
A01	16.41 ±0.22^{fghij}	3.07 ±0.03^{a}	0.56 ±0.02^{stuvw}	25.10 ±0.61^{b}	22.76 ±0.59^{b}	90.59 ±0.39^{bcde}
A02	15.39 ±0.27^{klmn}	2.61 ±0.05^{cd}	0.47 ±0.02$^{c'd'e'f'}$	16.43 ±0.67^{lmnop}	14.72 ±0.59^{jkl}	89.74 ±0.67^{bcdefg}
A03	16.51 ±0.35^{ghij}	2.83 ±0.06^{b}	0.51 ±0.02$^{wxyza'b'c'}$	21.55 ±1.06^{de}	19.70 ±0.98^{cd}	91.46 ±0.63^{abc}
A04	18.04 ±0.26^{bcd}	2.47 ±0.02^{ef}	0.77 ±0.02^{hij}	23.13 ±0.62^{cd}	20.49 ±0.54^{c}	88.67 ±0.39^{bcdefghij}
A05	16.63 ±0.28^{fghi}	1.74 ±0.02$^{yza'}$	0.57 ±0.01^{stuvw}	10.87 ±0.37$^{yzb'c'}$	8.51 ±0.34^{yz}	78.00 ±1.15$^{yza'}$
A06	12.85 ±0.18^{tuv}	1.74 ±0.03$^{yza'}$	0.87 ±0.02^{cdef}	15.03 ±0.44^{oqrst}	13.09 ±0.40^{mnop}	87.00 ±0.63^{ghijklmnop}
A07	14.87 ±0.27^{mnopq}	2.08 ±0.02^{nop}	0.78 ±0.01^{ghij}	14.73 ±0.43^{qrst}	12.47 ±0.34^{nopqr}	84.85 ±0.95^{nopqrstuv}
A08	14.44 ±0.21^{nopqr}	1.92 ±0.03^{tuv}	0.89 ±0.02^{cd}	19.30 ±0.58^{fghi}	17.17 ±0.53^{fgh}	88.92 ±0.67^{bcdefghi}
A09	12.14 ±0.18^{vwxy}	1.75 ±0.02$^{yza'}$	0.87 ±0.02^{cdef}	13.80 ±0.40^{rstv}	12.04 ±0.36^{nopqrs}	87.28 ±0.94^{fghijklmno}
A10	13.59 ±0.25^{rst}	1.76 ±0.02$^{xyza'}$	0.50 ±0.02$^{xyza'b'c'}$	7.83 ±0.25$^{e'}$	5.87 ±0.26$^{b'c'd'}$	74.19 ±1.55$^{b'c'}$
A11	18.42 ±0.21^{bc}	2.67 ±0.03^{c}	0.84 ±0.02^{ef}	27.40 ±0.55^{a}	24.73 ±0.51^{a}	90.22 ±0.30^{bcdef}
A12	15.50 ±0.18^{jklm}	2.37 ±0.03^{fghij}	0.82 ±0.02^{efg}	19.77 ±0.40^{efgh}	17.63 ±0.37^{fg}	89.20 ±0.60^{bcdefghi}
A13	13.46 ±0.31^{stu}	2.45 ±0.06^{ef}	0.73 ±0.02^{jk}	17.93 ±0.80^{ijkl}	15.96 ±0.71^{hijk}	89.11 ±0.77^{bcdefghi}
A14	13.43 ±0.26^{stu}	2.34 ±0.04^{ghij}	0.79 ±0.03^{ghi}	15.40 ±0.71^{nopqr}	13.60 ±0.65^{lmn}	88.06 ±0.98^{cefghijklm}
A15	14.26 ±0.22^{opqrs}	2.08 ±0.02^{nop}	0.60 ±0.02^{pqrstu}	12.43 ±0.48^{xy}	10.23 ±0.38^{uvwx}	82.52 ±0.75^{rstuvwxy}
A16	13.91 ±0.22^{qrs}	2.37 ±0.03^{fgh}	0.80 ±0.01^{ghi}	17.27 ±0.38^{jklmn}	14.90 ±0.34^{ijkl}	86.28 ±0.39^{ijklmnopq}
A17	14.14 ±0.23^{pqrs}	2.39 ±0.03^{fg}	0.75 ±0.01^{ijk}	16.77 ±0.49^{klmno}	14.69 ±0.42^{jkl}	87.78 ±0.79^{efghijklmn}
A18	11.34 ±0.19^{yz}	1.74 ±0.04$^{yza'}$	0.44 ±0.01$^{d'e'f'g'h'}$	5.80 ±0.21$^{f'}$	4.17 ±0.19$^{e'}$	71.37 ±1.59$^{d'}$
A19	16.56 ±0.25^{ghi}	1.95 ±0.03^{rstuv}	0.55 ±0.01$^{uvwxyza'}$	13.20 ±0.31^{tuwx}	10.61 ±0.27^{stuvw}	80.39 ±0.68$^{yza'}$
A20	15.19 ±0.41^{lmno}	2.02 ±0.05^{opqrst}	0.92 ±0.02^{abc}	17.03 ±0.88^{jklmno}	15.20 ±0.83^{ijk}	89.14 ±0.83^{bcdefghi}
A21	16.86 ±0.37^{fghi}	2.19 ±0.04^{kl}	0.86 ±0.02^{def}	20.00 ±0.88^{efg}	17.67 ±0.87^{efg}	87.84 ±0.85^{efghijklmn}
A22	17.88 ±0.38^{bcde}	2.42 ±0.03^{fg}	0.80 ±0.03^{fgh}	23.07 ±1.04^{cd}	20.47 ±0.94^{c}	88.79 ±0.58^{bcdefghi}
A23	15.39 ±0.31^{klmn}	1.98 ±0.02^{qrstu}	0.63 ±0.02^{nopqr}	13.60 ±0.54^{rstvw}	11.46 ±0.51^{qrstu}	83.98 ±1.05^{pqrstuvw}
A24	14.94 ±0.26^{mnop}	2.64 ±0.03^{c}	0.64 ±0.01^{mnopqr}	20.10 ±0.53^{ef}	18.46 ±0.52^{def}	91.69 ±0.18^{ab}
A25	18.34 ±0.36^{bc}	2.70 ±0.06^{c}	0.91 ±0.02^{bcd}	26.67 ±1.20^{a}	25.03 ±1.17^{a}	93.66 ±0.54^{a}
A26	16.99 ±0.37^{efgh}	2.27 ±0.04^{hjk}	0.84 ±0.02^{efg}	24.03 ±0.86^{bc}	22.56 ±0.82^{b}	93.80 ±0.24^{a}
A27	15.49 ±0.21^{jklm}	2.39 ±0.02^{fg}	0.63 ±0.01^{nopqr}	18.20 ±0.44^{hijkl}	16.09 ±0.39^{hij}	88.43 ±0.39^{cdefghijk}
A28	16.03 ±0.24^{ijkl}	2.55 ±0.02^{de}	0.63 ±0.02^{opqr}	19.87 ±0.55^{efgh}	17.69 ±0.49^{efg}	89.13 ±0.47^{bcdefghi}
A29	14.14 ±0.28^{pqrs}	2.19 ±0.02^{kl}	0.59 ±0.01^{qrstuv}	12.70 ±0.32^{tuxy}	10.56 ±0.27^{stuvw}	83.13 ±0.49^{rstuvwx}
A30	14.91 ±0.23^{mnop}	1.73 ±0.02$^{yza'}$	0.49 ±0.01$^{c'd'e'}$	8.63 ±0.23$^{d'e'}$	6.63 ±0.21$^{a'b'}$	76.85 ±1.31$^{za'}$
A31	15.94 ±0.29^{ijkl}	2.41 ±0.02^{fg}	0.60 ±0.01^{pqrstuv}	17.37 ±0.46^{jklm}	15.21 ±0.39^{ijk}	87.72 ±0.43^{efghijklmn}
A32	12.89 ±0.31^{tuv}	2.18 ±0.03^{klmn}	0.49 ±0.01$^{ya'b'c'}$	9.70 ±0.39$^{c'd'}$	8.40 ±0.34^{yz}	86.63 ±0.72^{ghijklmnopq}
A33	11.64 ±0.30^{xyz}	1.86 ±0.03^{vwx}	0.61 ±0.01^{pqrst}	9.67 ±0.40$^{c'd'}$	7.76 ±0.31$^{yza'}$	80.75 ±1.02^{xyz}
A34	11.20 ±0.30^{z}	2.00 ±0.04^{pqrst}	0.57 ±0.02^{stuvw}	9.60 ±0.37$^{c'd'}$	8.57 ±0.31^{yz}	89.45 ±0.48^{bcdefgh}
A35	12.56 ±0.26^{uvwx}	2.18 ±0.03^{klm}	0.55 ±0.01^{tuvwxy}	11.23 ±0.33$^{xyb'c'}$	9.35 ±0.24^{vwxy}	83.82 ±1.29^{qrstuvwx}
A36	15.12 ±0.35^{lmno}	1.98 ±0.05^{pqrstu}	0.50 ±0.02$^{yza'b'c'}$	12.93 ±0.55^{tuxy}	10.89 ±0.47^{rstuv}	84.20 ±0.60^{pqrstuvw}
A37	14.67 ±0.25^{mnopq}	1.80 ±0.02^{wxyz}	0.62 ±0.01^{pqrs}	13.23 ±0.41^{tuwx}	10.84 ±0.34^{stuv}	82.03 ±0.95^{suwxy}
A38	17.94 ±0.43^{bcd}	1.93 ±0.02^{stuv}	0.43 ±0.01$^{e'f'g'h'}$	13.90 ±0.55^{qrstv}	11.98 ±0.45^{opqrst}	86.50 ±0.69^{hijklmnopq}
A39	12.71 ±0.31^{tuv}	1.80 ±0.03^{wxyz}	0.57 ±0.01^{stuvw}	10.03 ±0.46$^{a'c'd'}$	8.40 ±0.43^{yz}	83.24 ±1.09^{rstuvwx}
A40	14.51 ±0.22^{nopqr}	1.95 ±0.02^{rstuv}	0.48 ±0.01$^{c'd'e'f'}$	11.17 ±0.35$^{yzb'c'}$	9.13 ±0.27^{wxy}	82.07 ±0.98^{suwxy}
A41	15.29 ±0.29^{lmn}	2.03 ±0.02^{opqrs}	0.50 ±0.02$^{xyza'b'c'}$	12.70 ±0.53^{tuxy}	10.37 ±0.46^{tuvwx}	81.38 ±0.69^{wxyz}
A42	16.30 ±0.27^{hijk}	2.11 ±0.02^{lmno}	0.59 ±0.02^{pqrstuv}	15.07 ±0.42^{nopqrs}	12.86 ±0.42^{nopq}	85.08 ±0.66^{mnopqrstuv}
A43	18.38 ±0.40^{bc}	2.37 ±0.03^{fghi}	0.95 ±0.02^{ab}	24.67 ±0.66^{bc}	21.96 ±0.63^{b}	88.88 ±0.31^{bcdefghi}
A44	11.75 ±0.23^{wxyz}	1.54 ±0.04$^{b'}$	0.45 ±0.01$^{c'd'e'f'g'}$	6.17 ±0.20$^{e'f'}$	4.60 ±0.20$^{c'd'e'}$	74.35 ±1.60$^{b'c'}$
A45	17.50 ±0.37^{cdef}	2.45 ±0.03^{ef}	0.71 ±0.02^{k}	21.48 ±0.87^{de}	19.28 ±0.77^{cde}	89.88 ±0.74^{bcdefg}
A46	16.32 ±0.29^{hijk}	2.44 ±0.03^{fg}	0.76 ±0.02^{ij}	20.30 ±0.44^{ef}	18.06 ±0.42^{def}	88.86 ±0.43^{bcdefghi}
A47	12.21 ±0.19^{vwxy}	1.88 ±0.02^{uvw}	0.97 ±0.02^{a}	17.27 ±0.48^{jklmno}	15.77 ±0.45^{hijk}	91.31 ±0.46^{abcd}
A48	17.52 ±0.34^{cdef}	2.44 ±0.02^{fg}	0.69 ±0.02^{kl}	20.33 ±0.62^{ef}	18.03 ±0.52^{def}	88.81 ±0.48^{bcdefghi}
A49	12.04 ±0.15^{vwxyz}	1.76 ±0.02$^{xyza'}$	0.97 ±0.02^{a}	16.10 ±0.36^{mnopq}	14.41 ±0.30^{klm}	89.64 ±0.60^{bcdefgh}
A50	18.65 ±0.31^{ab}	2.47 ±0.02^{ef}	0.55 ±0.02^{tuvwxyz}	17.93 ±0.55^{ijkl}	15.82 ±0.49^{hijk}	88.26 ±0.56^{cdefghijkl}
A51	14.83 ±0.22^{mnopq}	2.37 ±0.03^{fg}	0.88 ±0.02^{cde}	18.67 ±0.49^{fghij}	16.43 ±0.44^{ghi}	88.11 ±0.72^{cefghijklm}
A52	15.58 ±0.30^{jklm}	1.77 ±0.03^{xyz}	0.34 ±0.02$^{j'k'}$	9.03 ±0.38$^{d'e'}$	7.17 ±0.30$^{za'b'}$	79.68 ±1.17$^{yza'}$
A53	15.25 ±0.22^{lmn}	1.74 ±0.03$^{yza'}$	0.39 ±0.02$^{h'i'}$	10.00 ±0.32$^{c'd'}$	8.17 ±0.29^{yz}	81.55 ±1.23^{wxyz}
A54	15.94 ±0.24^{ijkl}	1.99 ±0.05^{pqrst}	0.55 ±0.03^{tuvwx}	13.50 ±0.48^{stvwx}	11.49 ±0.49^{pqrstu}	84.62 ±0.93^{opqrstuv}
A55	16.01 ±0.21^{ijkl}	2.44 ±0.04^{fg}	0.66 ±0.01^{klm}	18.33 ±0.50^{ghijk}	16.23 ±0.49^{ghij}	88.42 ±0.68^{cdefghijk}
A56	14.63 ±0.27^{mnopq}	1.71 ±0.04$^{za'}$	0.38 ±0.02$^{i'j'}$	7.73 ±0.47$^{e'}$	5.98 ±0.43$^{b'c'}$	75.91 ±1.69$^{a'b'}$
A57	12.55 ±0.22^{uvwx}	1.57 ±0.02$^{b'}$	0.47 ±0.01$^{c'd'e'f'}$	6.03 ±0.16$^{f'}$	4.34 ±0.17$^{d'e'}$	71.47 ±1.57$^{d'}$
A58	12.10 ±0.22^{vwxyz}	1.66 ±0.02$^{a'}$	0.39 ±0.01$^{h'i'}$	6.63 ±0.32$^{e'f'}$	4.84 ±0.29$^{c'd'e'}$	72.30 ±1.66$^{c'd'}$
A59	16.10 ±0.26^{hijkl}	2.43 ±0.03^{fg}	0.65 ±0.02^{lmnopq}	20.32 ±0.60^{ef}	17.79 ±0.54^{efg}	87.53 ±0.52^{efghijklmno}
A60	19.36 ±0.35^{a}	2.06 ±0.03^{opqr}	0.40 ±0.02$^{g'h'i'}$	13.61 ±0.44^{pqrstv}	11.61 ±0.45^{pqrstu}	85.10 ±0.92^{lmnopqrstu}
A61	14.27 ±0.13^{opqrs}	1.71 ±0.02$^{za'}$	0.29 ±0.02$^{k'}$	5.97 ±0.15$^{f'}$	4.80 ±0.16$^{c'd'e'}$	80.51 ±1.74^{xyz}
A62	17.35 ±0.38^{defg}	2.12 ±0.04^{lmno}	0.48 ±0.02$^{c'd'e'f'}$	15.75 ±0.81^{mnopqr}	13.50 ±0.76^{lmno}	85.35 ±0.95^{klmnopqrst}
A63	14.47 ±0.69^{nopqr}	2.08 ±0.04^{mnopq}	0.42 ±0.01$^{f'g'h'i'}$	10.19 ±0.73$^{za'c'd'}$	8.34 ±0.57^{yz}	82.96 ±1.07^{rstuvwxy}
A64	14.05 ±0.34^{pqrs}	1.97 ±0.03^{qrstu}	0.54 ±0.01$^{vwxyza'b'}$	12.64 ±0.55^{uxy}	10.80 ±0.47^{stuv}	85.60 ±0.80^{jklmnopqr}
A65	12.63 ±0.34^{uvw}	1.96 ±0.03^{rstuv}	0.49 ±0.01$^{b'c'd'}$	10.83 ±0.43$^{za'c'}$	8.92 ±0.35^{xy}	82.66 ±1.09^{rstuvwxy}
A66	14.89 ±0.62l^{mnopq}	1.85 ±0.05^{uvwxy}	0.58 ±0.03^{rstuvw}	13.60 ±1.21^{stvwx}	11.60 ±1.02^{opqrstu}	85.43 ±0.70^{ijklmnopqrs}

Acc: Accession. Means with different letters in the same column differ significantly ($p < 0.05$). * Significantly different at $P < 0.001$.

Supplementary table 3. Seed characteristics of 66 Algerian carob trees accessions.

Acc	Length (cm)*	Width (cm)*	Thickness (cm)*	Weight of seeds*	Number of seeds*	% of seeds*
A01	0.92 ±0.01^{lmnopq}	0.81 ±0.00^{a}	0.44 ±0.00^{efg}	2.34 ±0.09^{abcdefgh}	10.40 ±0.23^{qrstuvwx}	9.41 ±0.39$^{xyza'}$
A02	0.87 ±0.01$^{xyza'b'c'd'}$	0.74 ±0.00^{dfhijkl}	0.41 ±0.00^{klmnopq}	1.71 ±0.13^{qrstuvwxy}	9.60 ±0.35$^{vwxyza'b'c'd'}$	10.26 ±0.67$^{vwxyza'}$
A03	0.90 ±0.01^{qrstuvwx}	0.77 ±0.01^{bcd}	0.41 ±0.00^{klmnopqrst}	1.85 ±0.15^{ijklmnopqrstuvwx}	9.55 ±0.48$^{wxyza'b'c'd'}$	8.54 ±0.63$^{yza'b'}$
A04	1.09 ±0.01^{ab}	0.75 ±0.01^{cdefghij}	0.41 ±0.00^{jklmn}	2.64 ±0.12^{abc}	12.20 ±0.29^{cdefg}	11.33 ±0.39$^{rstuvwxyza'}$
A05	0.94 ±0.01^{klmn}	0.72 ±0.00^{mnopqr}	0.47 ±0.00^{b}	2.36 ±0.11^{abcdefg}	12.20 ±0.35^{cdefg}	22.00 ±1.15^{de}
A06	0.89 ±0.01^{stuvwxy}	0.61 ±0.01$^{l'm'}$	0.41 ±0.01^{klmnopqrstuv}	1.95 ±0.10^{ghijklmnopqrstuv}	12.83 ±0.35^{abcd}	13.00 ±0.63^{lmnopqrstuv}
A07	1.07 ±0.01^{b}	0.70 ±0.00$^{uvwxyza'}$	0.39 ±0.00^{wxyz}	2.27 ±0.16^{bcdefghijk}	11.17 ±0.39^{fghijklmnopqrstu}	15.15 ±0.95^{ijklmn}
A08	0.86 ±0.01$^{c'd'e'}$	0.59 ±0.01$^{n'}$	0.36 ±0.01$^{b'c'd'e'}$	2.13 ±0.14^{efghijklmnopq}	13.50 ±0.46^{ab}	11.08 ±0.67$^{rtuvwxyza'}$
A09	0.90 ±0.00^{stuvwx}	0.62 ±0.00$^{i'j'k'}$	0.42 ±0.00^{ijkl}	1.76 ±0.14^{pqrstuvwx}	11.43 ±0.39^{defghijklmnopqrs}	12.72 ±0.94^{mnopqrstuvw}
A10	0.86 ±0.01$^{c'd'e'f'}$	0.68 ±0.01$^{b'c'd'e'f'}$	0.41 ±0.00^{jklmnop}	1.97 ±0.11^{fghijklmnopqrstuv}	11.83 ±0.40^{defghijklmno}	25.81 ±1.55^{bc}
A11	0.95 ±0.01^{jkl}	0.77 ±0.01^{bcde}	0.41 ±0.00^{jklmnopq}	2.67 ±0.08^{ab}	13.43 ±0.26^{abc}	9.78 ±0.30$^{wxyza'}$
A12	0.92 ±0.01^{mnopqrs}	0.71 ±0.01^{opqrstuvwx}	0.40 ±0.00^{mnopqrstuvw}	2.14 ±0.13^{efghijklmnopq}	12.40 ±0.32^{bcde}	10.80 ±0.60$^{rtuvwxyza'}$
A13	0.84 ±0.01$^{e'f'g'}$	0.67 ±0.01$^{e'f'g'}$	0.46 ±0.01^{cd}	1.97 ±0.17^{fghijklmnopqrstuv}	11.79 ±0.66^{defghijklmnop}	10.89 ±0.77$^{rtuvwxyza'}$
A14	0.87 ±0.01$^{ya'b'c'd'}$	0.72 ±0.01^{mnopqr}	0.38 ±0.01$^{yza'}$	1.80 ±0.14^{lnopqrstuvwx}	9.50 ±0.41$^{xyza'b'c'd'}$	11.94 ±0.98^{opqrstuvwxy}
A15	0.91 ±0.01^{opqrst}	0.69 ±0.01$^{yza'b'c'd'e'}$	0.41 ±0.00^{klmnopqrs}	2.20 ±0.14^{defghijklmno}	10.43 ±0.42^{qrstuvwx}	17.48 ±0.75^{fghij}
A16	0.93 ±0.01^{lmnop}	0.69 ±0.01$^{wxyza'b'c'd'}$	0.43 ±0.00^{fgh}	2.36 ±0.08^{abcdefg}	12.40 ±0.28^{bcde}	13.72 ±0.39^{klmnopqrst}
A17	0.94 ±0.01^{klmno}	0.75 ±0.00^{dfghijk}	0.47 ±0.00^{bc}	2.08 ±0.15^{fghijklmnopqr}	10.00 ±0.44$^{tuvwxyzb'c'd'}$	12.22 ±0.79^{nopqrstuvwx}
A18	0.91 ±0.01^{pqrst}	0.71 ±0.01^{opqrstuv}	0.50 ±0.00^{a}	1.63 ±0.09^{stuvwxy}	8.47 ±0.27$^{b'd'}$	28.63 ±1.59^{a}
A19	0.96 ±0.00^{ij}	0.69 ±0.00$^{za'b'c'd'e'}$	0.41 ±0.00^{klmnopqr}	2.59 ±0.10^{abcd}	13.97 ±0.45^{a}	19.61 ±0.68^{efg}
A20	1.02 ±0.01^{ef}	0.67 ±0.01$^{c'd'e'f'g'}$	0.39 ±0.00$^{wxyza'}$	1.83 ±0.16^{klmnopqrstuvwx}	9.77 ±0.56$^{uvwxyza'b'c'd'}$	10.86 ±0.83$^{rtuvwxyza'}$
A21	1.05 ±0.01^{c}	0.71 ±0.01^{opqrstu}	0.40 ±0.00^{qrstuvwxy}	2.33 ±0.14^{abcdefghi}	11.43 ±0.44^{defghijklmnopqrs}	12.16 ±0.85^{nopqrstuvwx}
A22	0.99 ±0.01^{egh}	0.70 ±0.01^{uvwxyz}	0.37 ±0.01$^{za'b'c'}$	2.59 ±0.17^{abcd}	11.70 ±0.42^{defghijklmnop}	11.21 ±0.58$^{rtuvwxyza'}$
A23	0.95 ±0.01^{jkl}	0.69 ±0.00$^{vwxyza'b'c'}$	0.36 ±0.00$^{d'e'}$	2.14 ±0.15^{efghijklmnopq}	10.77 ±0.43^{lmnopqrstuvw}	16.02 ±1.05^{hijkl}
A24	0.81 ±0.01$^{h'}$	0.70 ±0.01^{tuvwxyz}	0.31 ±0.00$^{f'}$	1.64 ±0.02^{stuvwxy}	8.80 ±0.22$^{yza'b'c'd'}$	8.31 ±0.18$^{a'b'}$
A25	0.97 ±0.01^{ij}	0.73 ±0.01^{lmnopq}	0.23 ±0.01$^{h'}$	1.63 ±0.13^{stuvwxy}	9.83 ±0.43$^{tuvwxyza'b'c'd'}$	6.34 ±0.54$^{b'}$
A26	0.99 ±0.01^{gh}	0.74 ±0.01^{dfhijkl}	0.25 ±0.01$^{g'}$	1.48 ±0.07^{uxyz}	8.77 ±0.31$^{zb'c'd'}$	6.20 ±0.24$^{b'}$
A27	0.90 ±0.01^{qrstuv}	0.78 ±0.00^{b}	0.39 ±0.00^{tvwxyz}	2.11 ±0.09^{efghijklmnopqr}	11.67 ±0.27^{defghijklmnopq}	11.57 ±0.39^{qrstuvwxyz}
A28	0.92 ±0.01^{mnopqr}	0.78 ±0.00^{b}	0.38 ±0.00$^{xyza'}$	2.17 ±0.12^{defghijklmnop}	11.87 ±0.30^{defghijklmn}	10.87 ±0.47$^{rtuvwxyza'}$
A29	0.96 ±0.01^{ijk}	0.74 ±0.00^{jklmn}	0.39 ±0.00$^{wxyza'}$	2.14 ±0.09^{efghijklmnopq}	12.07 ±0.33^{defghijk}	16.87 ±0.49^{ghij}
A30	0.88 ±0.01$^{wxyza'b'c'd'}$	0.68 ±0.00$^{b'c'd'e'f'}$	0.41 ±0.00^{jklmnop}	2.00 ±0.12^{fghijklmnopqrst}	12.07 ±0.27^{defghijkl}	23.15 ±1.31^{cd}
A31	0.91 ±0.00^{pqrst}	0.76 ±0.00^{bcdefg}	0.39 ±0.00^{rstuvwxy}	2.15 ±0.10^{efghijklmnop}	12.33 ±0.32^{bcdef}	12.28 ±0.43^{nopqrstuvwx}
A32	0.84 ±0.01$^{f'g'}$	0.64 ±0.01$^{i'}$	0.38 ±0.00$^{xyza'}$	1.30 ±0.09$^{yza'}$	9.00 ±0.34$^{yza'b'c'd'}$	13.37 ±0.72^{klmnopqrstuv}
A33	0.82 ±0.01$^{g'h'}$	0.69 ±0.01$^{yza'b'c'd'}$	0.47 ±0.00^{bc}	1.90 ±0.14^{ijklmnopqrstuvwx}	11.33 ±0.45^{efghijklmnopqrst}	19.25 ±1.02^{efg}
A34	0.82 ±0.01$^{g'h'}$	0.67 ±0.01$^{c'd'e'f'g'}$	0.40 ±0.00^{npqrstuvwx}	1.03 ±0.08$^{a'}$	6.43 ±0.42$^{e'}$	10.55 ±0.48$^{uvwxyza'}$
A35	0.86 ±0.00$^{d'e'f'}$	0.68 ±0.00$^{za'b'c'd'e'f'}$	0.42 ±0.00^{hijk}	1.88 ±0.17^{jklmnopqrstuvwx}	10.93 ±0.37^{ghijklmnopqrstuv}	16.18 ±1.29^{hijk}
A36	0.90 ±0.01^{rstuvw}	0.67 ±0.01$^{f'g'}$	0.41 ±0.00^{jklmnop}	2.05 ±0.11^{fghijklmnopqrs}	11.27 ±0.45^{efghijklmnopqrstu}	15.80 ±0.60^{hijkl}
A37	0.88 ±0.01$^{uwxyza'b'c'}$	0.66 ±0.01$^{h'}$	0.36 ±0.01$^{d'e'}$	2.39 ±0.15^{abcdef}	11.27 ±0.29^{efghijklmnopqrstu}	17.97 ±0.95^{fghi}
A38	1.01 ±0.00^{efg}	0.74 ±0.00^{fijklm}	0.39 ±0.00^{stuvwxyz}	1.92 ±0.14^{hijklmnopqrstuvw}	10.60 ±0.43^{nopqrstuvw}	13.50 ±0.69^{klmnopqrstu}
A39	0.93 ±0.01^{klmno}	0.71 ±0.01^{opqrstuv}	0.43 ±0.00^{ghij}	1.63 ±0.11^{stuvwxy}	9.73 ±0.36$^{tuvwxyza'b'c'd'}$	16.76 ±1.09^{ghij}
A40	1.01 ±0.00^{efg}	0.71 ±0.00^{rstuvwxy}	0.40 ±0.00^{lmnopqrstuv}	2.03 ±0.14^{fghijklmnopqrs}	10.90 ±0.33^{hjklmnopqrstuv}	17.93 ±0.98^{fghi}
A41	1.01 ±0.01^{efg}	0.72 ±0.00^{mnopqr}	0.39 ±0.00^{twxyz}	2.33 ±0.10^{abcdefghi}	12.20 ±0.32^{cdefgh}	18.62 ±0.69^{fgh}
A42	1.04 ±0.01^{cd}	0.76 ±0.00^{cdefghi}	0.40 ±0.00^{mnopqrstuvw}	2.21 ±0.09^{defghijklmno}	10.67 ±0.25^{lmnopqrstuvw}	14.92 ±0.66^{jklmno}
A43	1.09 ±0.01^{ab}	0.76 ±0.01^{bcdefgh}	0.41 ±0.00^{klmnopqrs}	2.71 ±0.07^{a}	12.13 ±0.36^{defghij}	11.12 ±0.31$^{rtuvwxyza'}$
A44	0.87 ±0.01$^{xyza'b'c'd'}$	0.74 ±0.01^{jklmn}	0.47 ±0.01^{b}	1.57 ±0.10^{tuvwxy}	8.77 ±0.31$^{b'c'd'}$	25.65 ±1.60^{bc}
A45	1.10 ±0.01^{a}	0.76 ±0.01^{bcdefgh}	0.41 ±0.00^{klmnopqrstu}	2.20 ±0.17^{defghijklmnop}	10.26 ±0.43^{qstuvwxy}	10.12 ±0.74$^{vwxyza'}$
A46	1.04 ±0.01^{c}	0.70 ±0.01$^{uvwxyza'b'}$	0.37 ±0.01$^{a'b'c'd'e'}$	2.25 ±0.09^{cdefghijklm}	10.57 ±0.30^{oqrstuvw}	11.14 ±0.43$^{rtuvwxyza'}$
A47	0.91 ±0.01^{pqrst}	0.60 ±0.01$^{m'n'}$	0.48 ±0.01^{b}	1.50 ±0.09^{uwxyz}	9.73 ±0.43$^{vwxyza'b'c'd'}$	8.69 ±0.46$^{za'b'}$
A48	1.07 ±0.01^{b}	0.72 ±0.00^{mnopqrs}	0.40 ±0.00^{mnopqrstuvw}	2.31 ±0.13^{abcdefghij}	12.00 ±0.40^{defghijklm}	11.19 ±0.48$^{rtuvwxyza'}$
A49	0.89 ±0.01^{tuvwxyz}	0.62 ±0.00$^{j'k'l'}$	0.50 ±0.00^{a}	1.69 ±0.11^{rstuvwxy}	10.63 ±0.45^{mnopqrstuvw}	10.36 ±0.60$^{uvwxyza'}$
A50	1.02 ±0.01^{ef}	0.69 ±0.01$^{yza'b'c'd'}$	0.40 ±0.00^{qrstuvwxy}	2.12 ±0.13^{efghijklmnopqr}	11.70 ±0.46^{defghijklmnop}	11.74 ±0.56^{pqrstuvwxyz}
A51	0.85 ±0.01$^{d'e'f'}$	0.66 ±0.01$^{i'}$	0.45 ±0.01^{de}	2.23 ±0.15^{cdefghijklmn}	12.43 ±0.41^{bcde}	11.89 ±0.72^{opqrstuvwxy}
A52	0.91 ±0.01^{pqrstuv}	0.71 ±0.01^{opqrstuvwx}	0.42 ±0.00^{ijkl}	1.86 ±0.14^{klmnopqrstuvwx}	10.77 ±0.47^{hklmnopqrstuv}	20.32 ±1.17^{ef}
A53	0.91 ±0.01^{opqrst}	0.69 ±0.01$^{yza'b'c'd'}$	0.41 ±0.00^{jklm}	1.83 ±0.13^{klmnopqrstuvwx}	11.57 ±0.34^{defghijklmnopqr}	18.45 ±1.23^{fgh}
A54	0.87 ±0.01$^{b'c'd'}$	0.68 ±0.01$^{a'b'c'd'e'f'}$	0.41 ±0.01^{lmnopqrstuv}	2.01 ±0.11^{fghijklmnopqrs}	12.27 ±0.32^{bcdefg}	15.38 ±0.93^{ijklm}
A55	0.86 ±0.01$^{b'c'd'e'}$	0.71 ±0.01^{pqrstuvwxy}	0.41 ±0.00^{jklmno}	2.10 ±0.12^{efghijklmnopqr}	11.93 ±0.27^{defghijklm}	11.58 ±0.68^{qrstuvwxyz}
A56	0.92 ±0.01^{lmnopq}	0.70 ±0.01^{stuvwxy}	0.44 ±0.00^{ef}	1.75 ±0.12^{pqrstuvwx}	10.70 ±0.39^{lmnopqrstuvw}	24.09 ±1.69^{cd}
A57	0.88 ±0.00$^{uvwxyza'b'c'}$	0.71 ±0.00^{rstuvwxy}	0.42 ±0.00^{ijkl}	1.69 ±0.08^{rstuvwxy}	9.67 ±0.25$^{vwxyza'b'c'd'}$	28.53 ±1.57^{a}
A58	0.92 ±0.01^{mnopqr}	0.72 ±0.01^{nopqrst}	0.40 ±0.00^{lmnopqrstuv}	1.79 ±0.11^{lopqrstuvwx}	10.10 ±0.24^{pqrstuvwxy}	27.70 ±1.66^{ab}
A59	1.02 ±0.01^{de}	0.77 ±0.01^{bc}	0.44 ±0.01^{ef}	2.53 ±0.13^{abcde}	12.16 ±0.34^{bcdefghij}	12.47 ±0.52^{mnopqrstuvwx}
A60	0.89 ±0.00$^{stuvwxyza'}$	0.71 ±0.00^{qrstuvwxy}	0.41 ±0.00^{klmnopqrs}	2.00 ±0.12^{fghijklmnopqrst}	12.74 ±0.38^{abcde}	14.90 ±0.92^{ijklmnop}
A61	0.82 ±0.00$^{g'h'}$	0.67 ±0.01$^{g'h'}$	0.37 ±0.00$^{za'b'c'd'}$	1.17 ±0.11$^{za'}$	9.37 ±0.37$^{yza'b'c'd'}$	19.49 ±1.74^{efg}
A62	0.98 ±0.01^{hi}	0.73 ±0.01^{klmnop}	0.44 ±0.01^{efg}	2.25 ±0.14^{bcdefghijkl}	11.38 ±0.41^{defghijklmnopqrs}	14.65 ±0.95^{jklmnopq}
A63	0.94 ±0.01^{klm}	0.72 ±0.01^{mnopqrs}	0.44 ±0.00^{ef}	1.85 ±0.18^{klmnopqrstuvwx}	10.04 ±0.73$^{tuvwxyzb'c'}$	17.04 ±1.07^{ghij}
A64	0.94 ±0.01^{klmno}	0.73 ±0.00^{klmno}	0.43 ±0.00^{fghi}	1.85 ±0.14^{klmnopqrstuvwx}	10.07 ±0.37$^{tuvwxyb'}$	14.40 ±0.80^{jklmnopqrs}
A65	0.91 ±0.01^{pqrst}	0.72 ±0.01^{mnopqr}	0.48 ±0.00^{b}	1.91 ±0.15^{hijklmnopqrstuvw}	10.63 ±0.38^{mnopqrstuvw}	17.34 ±1.09^{ghij}
A66	0.91 ±0.01^{opqrstu}	0.76 ±0.01^{bcdef}	0.47 ±0.01^{bc}	2.00 ±0.21^{efghijklmnopqrstu}	10.00 ±0.69$^{tuvwxyza'b'c'd'}$	14.57 ±0.70^{ijklmnopqr}

Acc: Accession. Means with different letters in the same column differ significantly ($p < 0.05$). * Significantly different at $P < 0.001$.