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Analysis of infraspecific taxa of *Arum italicum* (*Araceae*) using morphological and ecological data

Abstract

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Several infraspecific taxa within *Arum italicum* have been reported for the Iberian Peninsula and the Balearic Islands. Nevertheless morphological distinction of these taxa is made difficult by very high individual variation within the whole specific population. In order to provide new suitable additional characters for a better infraspecific distinction an ecological method has been tried. A Digital Terrain Model (DTM) of the studied area was elaborated in order to obtain, by an interpolation process, geographical and meteorological information for each plant locality. Canonical redundance analysis was run to evaluate relationships between morphological data and environmental variables, and the Mantel test was used to evaluate the influence of the spatial distribution on the plant localities.

Introduction

Arum italicum presents a high morphological variation in the Iberian Peninsula. Due to this fact, several infraspecific taxa have been described from this area. However, the impact of ecology on morphological variation has rarely been considered.

A. italicum s. l. is a species with a wide distribution. According to Bonnier (1931), Meusel & al. (1965), Dihoru (1970) and Bedalov (1981) its range extends from the Caucasus to the Atlantic coast through the Mediterranean region.

The taxa studied here are *A. italicum* Miller subsp. *italicum*, *A. italicum* subsp. *neglectum* (F. Towns.) Prime, *A. italicum* var. *pictum* Cout., and *A. italicum* subsp. *majoricense* (L. Chodat) O. Bolòs & al. (*A. majoricense* was described by Lucie Chodat and not by Robert Chodat. Therefore following the rules of Brummitt & Powell (1992) the standard form of these authors the standard form for Lucie Chodat will be "L. Chodat").

In the last revision of the genus (Boyce 1993) two subspecies of *A. italicum* are recognised in the studied area: subsp. *italicum*, widely distributed in the Iberian Peninsula, and subsp. *neglectum* which is reported by Talavera (1987) for southern Spain instead according to Boyce (1993) it occurs only in north-western Spain. *A. italicum* var.

pictum is represented by many herbarium specimens from all of Portugal. Lucie Chodat (1923) described *A. majoricense* from Majorca (Balearic Islands), which was considered by Bolòs & al. (1987) as a distinct subspecies of *A. italicum* and by Boyce (1993) included in subsp. *italicum*, being the only taxon occurring in the Balearic Islands.

It is to be noted that taxonomic studies on *A. italicum* are mainly based on morphological characters, whereas ecological parameters, like spatial and geographical distribution of plant stands, have not been considered. The present study is aimed at filling this gap.

Materials and methods

About six specimens from each locality were studied, and their biometric parameters were averaged to obtain a standard for each locality. Voucher specimens studied are deposited in the following herbaria: ABH, B, BC, BCC, C, COA, G, HBIL, JACA, JAEN, LEB, LISE, LISI, LISU, MA, MAF, MT, SANT, SEV and personal herbarium of the authors.

Morphological variables of *Arum italicum* s. l. from 78 localities of the Iberian Peninsula and Balearic Islands were measured and considered as a single information pool. The collecting localities are shown in Appendix 1. The morphological variables were classified as vegetative (60), inflorescence (75) and infructescence (12) (App. 2).

A Geographical Information System (GIS) was used to elaborate a Digital Terrain Model (DTM) that allows to interpolate environmental values of the localities. These ecological parameters were considered in the analysis of infraspecific taxa of *Arum italicum* and of morphological data.

The DTM was created from digital maps (1:250.000) for Portugal and from 500 square meters pixel dimension for Spain. A higher resolution for Portugal as compared to Spain was obtained because of the different data sources.

Geographical variables (latitude, longitude, altitude, slope and exposure) were recorded for each plant locality. Meteorological data (total and maximum precipitation, maximum, minimum and mean temperature, extreme maximum and extreme minimum temperature) from 119 meteorological stations were incorporated into the DTM in order to interpolate the values of these variables for each locality.

The two resulting data sets (one ecological including meteorological and geographical parameters, the other biological including biometrical parameters) were tested against each other. A redundance analysis was run to analyse the relationships between morphology and environmental parameters (Braak 1987) and, ultimately, to test the existing infraspecific classification of *Arum italicum*.

The significance of each canonic axis and of each variable was obtained from a Monte Carlo permutation. To test the presence of spatial autocorrelation between the different sample points based on the biometric measures a Mantel test (Legendre & Fortin 1989) was performed. The significance of Mantel's statistic was calculated by permuting the results of the Gower distance based on the biometric data and the geographical distance among simple sites, the null hypothesis being that there is no relation between the biometric data matrix and the geographical data.

Results

Several layers of information were obtained from the DTM (slope, exposure, altitude, latitude, longitude) and separately extracted for each plant locality. The exposure layer and the locations of the plant localities are shown in Fig. 1.

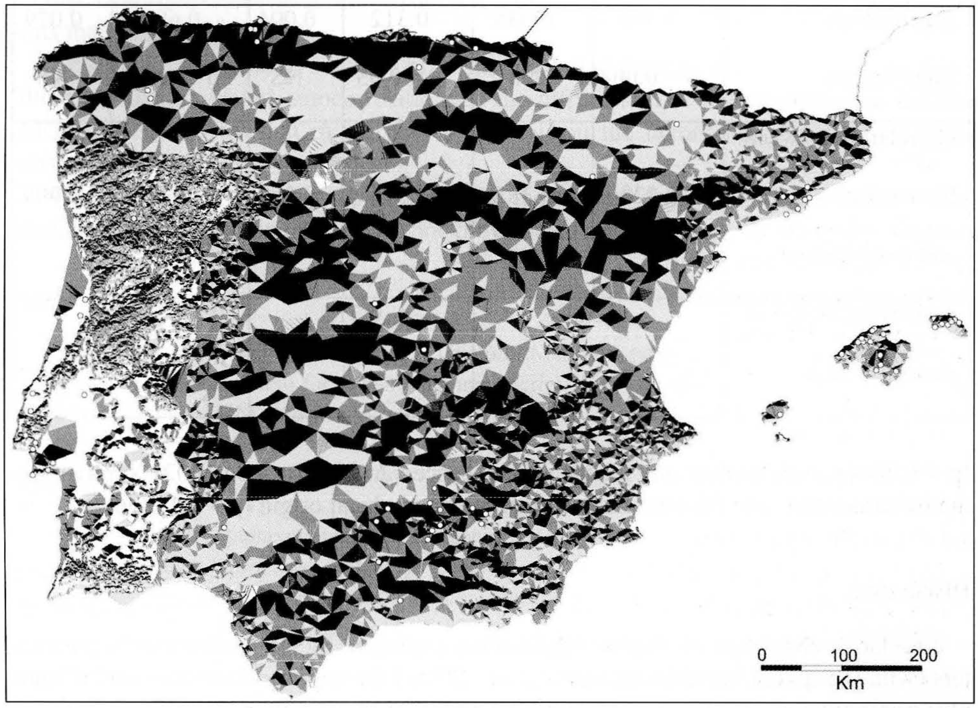

Fig. 1. Exposure information for the Iberian Peninsula. Flat zones are shown in white, exposures between 300° and 60° in black, between 60° and 135° and between 225° and 300° in dark-grey, between 135° and 225 ° in light grey (when N is at 0° and S at 180°). Circles denote the plant localities.

As far as the redundance analysis is concerned the first axis in Table 1 always explains the main variance ($p = 0.004$ for vegetative characters and infructescence; $p = 0.05$ for biometric inflorescence).

A forward selection of the environmental variables that significately explained biological variance (with $p < 0.1$) yielded c. 8 variables for each model, plus some non-significant variables that nevertheless substantially increase the power of the model (Table 1). The ecological data set explained 77% of the infructescence variance, 34% of the vegetative variance and only 24% of inflorescence variance. In the inflorescence model, the significant variables alone explain 15% of the variation. When the level of significance was set at $p < 0.05$ the infructescence variation only was explained by 39%, the vegetative variation by 34%, and the inflorescence variance was not explained (0%).

The Mantel test showed a very strong spatial autocorrelation for the vegetative variables

Table 1. Redundance analysis results. Two first axes fot the three biometrics models.

	Vegetative variables		Inflorescence variables		Infructescence variables	
	1^{st}	2^{ond}	1^{st}	2^{ond}	1^{st}	2^{ond}
Eigenvalues	0.305	0.036	0.312	0.004	0.696	0.079
Significance	$p <$ **0.004**	NS	$p =$ **0.05**	NS	$p <$ **0.004**	NS
Correlation between biometrical variables and environment	0.720	0.382	0.608	0.268	0.928	0.909
Sum of the first two canonical axes	0.356		0.312		0.775	

($p < 0.0001$) and a weaker one for the inflorescence variables ($p = 0.01402$); surprisingly, the infructescence variables are independent of geographical origin ($p = 0.18896$).

Discussion

Vegetative characters are highly significantly explained by the environmental parameters (with the spatial variables accounting for 27% of the explained variance and altitude plus minimum extreme temperature for 7%) and are completely spatially autocorrelated. These two results suggest that vegetative variance is strongly spatial structured (mainly along an east to west gradient) and are unsuited for purposes of taxonomic discrimination.

Inflorescence variables are those that least depend from ecological conditions, being best explained by meteorological data. The significant spatial autocorrelation may be related to coherence within discrete infraspecific taxa within *Arum italicum*, but the pattern of variation does not follow a longitude gradient. If one accepts taxa that are independent of an east-west gradient, then the inflorescence variables may be used to separate them.

Infructescence variables are strongly correlated with ecological factors, mainly spatial variables.

This result apparently conflicts with the non-significant Mantel test. However, a more detailed analysis of the data may help solving this conflict: the spatial variable that best explains the variance of infructescence structure is, once more, the longitude gradient, possibly reflecting some ecological condition related to the distance from the Mediterranean. Thus, differences in infructescence are unrelated to geographical distance but respond strongly to an east-west gradient. If infraspecific taxa are correlated with this trend, then infructescence biometry may help to define them.

Conclusion

A group of localities in Portugal is morphologically separated from the remainder. One explanation of this fact could be that Portuguese stands are in the periphery of the species distribution area. Another explanation could be that this work does not include Macaronesian material and the Portuguese specimens may be related with *Arum italicum* subsp. *canariense* (Webb & Berth.) Boyce. Further works will be necessary to elucidate this matter.

Either way, this pattern supports an assumption that there is a strong longitudinal gradient not due to spatial autocorrelation, as the infructescence model shows us, but to a Mediterranean factor that might play a key role in the taxonomical structuring of the observed variance of *Arum italicum*.

The inflorescence, not being explained by the model, may provide an important taxonomic criterion, accepting that we do not know which are the driving forces of this variation.

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Appendix 1. Localities data.

Country and province symbols are those in Castroviejo & al. (1986); UTM (Universal Transverse Mercator) grid square indications are explained in Rey (1984); voucher numbers are separated by brackets. The personal herbarium of the authors is indicated by ARG/DDM.

Hs: A: Dénia, Riu Girona, 31SBD4106, (ABH9335). **B:** Alella, 31TDF94, (BC603734, BC603735, BC603847). Argentona, 31TDG04, (BC620586). Can Bogunyà. Castellar del Vallès, 31TDG12, (HBIL12488). Cordillera del Tibidabo, 31TDF38, (BCC). La Roca del Vallès, 31TDG3495, (HBIL12481). Mataró, 31TDG5506, (JACA538669). Riera de Vallgorgina, 31TDG39, (BC620588). St. Just Desvern, 31TDF2383, (ARG/DDM). **Bi:** Bilbao: Peñascal de Arraitz, 30TWN07, (MA461042, MA164825, MA461044, MA164824). **Bu:** Leciñana de Mena, 30TVN6871, (JACA20676, HBIL12498). **Co:** Fuente Zarza. Zuheros, 30SUG85, (COA16562). Villa del Rio a Bujalance, 30SVG89, (COA6664). **Gr:** Jardines de la Alahambra, 30SVG0401, (C). **H:** Almonte. El Rocio, 29SQA29, (MA243953, MA243952, SEV93329, SEV58868). **Hu:** Benabarre, 31TBG9165, (JACA90176). **Ib:** Sta. Eulalia, Ibiza, 31SCD71, (BC97826). **J:** Garcíez. Orillas del río Bedmar, 30SVG5991, (JAEN82-261, JAEN80-508, JAEN80-507). La Carolina. Navas de Tolosa. El Organillo, 30SVH5437, (JAEN83742). Linares a Vadollano de Castro, 30SVH4719, (JAEN811102, JAEN920748, JAEN811103). Mancha Real a Jimena Cortijo de Maltocas, 30SVG4885, (JAEN930670). Marmolejo. Arroyo Bahondillo, 30SUH9515, (JAEN844588, JAEN844584, JAEN844586, JAEN844587, JAEN844585, JAEN844822). Pegajalar. Cerca del Guadalbullón, 30SVG4274, (JAEN832602). Santiago de la Espada. Aguas negras Caliz, 30SWH1602, (JAEN935041). Sierra de las Cuatro Villas, 30SWH01, (JAEN822342). Vilchez. Escudero, 31SVH61, (JAEN791081). **Lu:** Boveda, 29TPH2420, (SANT23230). Montforte. Barrioncas, 29TPH2212, (SANT24924). **M:** Villanueva de Perales. Río Perales, 30TVK0370, (MAF133720). **Mll:** 1 Km E of Puigpunyent, 31SDD68, (C3172). Alaró, 31SDD8393, (ARG/DDM). Alcúdia, 31SDD9264, (ARG/DDM). Bunyola, 31SDD79, (MA18603). Cala Pi, 31SDD8658, (ARG/DDM). Coll de Valldemosa, 31SDD6894, (ARG/DDM). Majorca. S'Orbeta, Bay of Alcúdia, 31SEE10, (MA18601, G). Monestir de Lluc, 31SDE9008, (MA18600). Puig Masanellas, 31SDE90, (B). Pujant a Lluc, 31SDE90, (ARG/DDM). Randa, 31SDD9374, (HBIL12487). Randa, 31SDD9375, (HBIL12484). Santanyí, 31SED15, (B). Sóller, 31SDD7398, (HBIL12485). **Mn:** Barranc d'Algendar. Ferreries., 31SEE8326, (JACA155057). Cap Favaritx, 31SFE0425, (ARG/DDM). Entre Es Mercadal i Es Migjorn Gran, 31SEE9024, (HBIL12495). Es Mercadal., 31SEE9527, (ARG/DDM). Ses Coves Velles, 31TEE9929, (HBIL12493). Son Catllar, 31SEE7423, (ARG/DDM). Son Servera., 31TEE9429, (ARG/DDM). Torre Petxina Vella, 31SEE8125, (HBIL12489). **O:** Arlós, Consejo de Llanera, 30TTP6519, (ARG/DDM). El Cristo-Oviedo, Consejo de Oviedo, 30TTP6704, (ARG/DDM). Salinas de Avilés, 30TTP64, (MAF1116, MAF1102). Xagó, Concejo de Gozón, 30TTP6432, (ARG/DDM). **Sa:** San Felices de los Gallegos, 29TTF93, (MA217616). **Se:** Carmona, 30STG65, (COA12479, SEV94656). **Sg:** Hontanares de Eresma, Lobones, 30TVL9935, (SANT26818). **SS:** Entre Deva y Motrico, 30TWN49, (LEB40270, MAF123729). **To:** Dos Barrios, 30SWK72, (MAF110504).

Lu: AAl: Serra de S. Mamede. Alvarroés, 29SPD45, (MA266489). **Ag:** Bodega, Tavira, 29SPB10, (MA390174). Serra de Monchique, 29SNB32, (MA266481). **BL:** Coimbr. Cidral, 29TNE45, (LISU1723). Mealhada, 29SNE4670, (ARG/DDM). **E:** Ameixoiera. pr. Lumiar, 29SMC78, (LISU7547). Cabo Espichel, 29SMC8657, (ARG/DDM). Mafra, 29SMD71, (MA151111, MA266487). Meco-Alfarim, 29CMC8254, (HBIL12476). Monte Pavor, 29SNC06, (ARG/DDM). Serra de São Luis, 29SNC0367, (ARG/DDM). Sierra de Arrábida, 29SNC05, (MT9977, LISU158414, LISE9977). Tapada d'Ajuda, 29SMC88, (LISU7555, LISU7558, LISU7557, LISI). Torres Vedras, 29SMD8032, (ARG/DDM). **R:** Ulme, 29SND4653, (HBIL12494). **TM:** UTAD, Vila Real, 29TPF0571, (HBIL12478).

Appendix 2. Morphological characters and characters states used.

Vegetative variables: Leaf-blade hastate; sagittate; hastate-sagittate; lanceolate-hastate. Length of leaf. Width of leaf. Leaf-apex obtuse; mucronate; acuminate; acute. Leaf with/without anthocyanin spots. Length of petiole. Width of petiole. Length of tuber. Width of tuber. Depth of tuber. Width/length ratio of leaf blade. Ratio length of leaf/length of petiole. Ratio width of tuber/length of tuber. Ratio depth of tuber/ width/length of tuber.

Infructescence variables: Fruiting spike cylindric; globose-elongate; spike cylindric-elongate; oblong-pyriform. Length of fruiting spike. Width of fruiting spike. Length of fruiting peduncle. Berries pyriform; pyriform-angular; pyriform-oblong; oblong; oblong-globose. Seeds oblong; elliptic; plane; spherical. Berry width (average). Seed width (average). Berry length (average). Seed length (average). Seed number per berry (average).

Inflorescence variables: Ovaries globose; globose-oblong; oblong; oblong-cylindric; ovoid. Length of ovary. Ratio length of peduncle at flowering/length of petiole. Width of spathe tube. Width of spathe limb. Width of appendix. Width of staminate flowers zone. Width of fruiting peduncle. Width of lower staminode zone. Width of pistillate flower zone. Spathe tube constricted, not constricted. Apex of spathe limb erect, not erect. Spathe limb apex mucronate; acuminate; narrowly acuminate; cucullate. Lower staminodes erect, not erect. Apex of lower staminodes narrow filiform; filiform. Upper staminodes erect, not erect. Upper staminodes filiform; subulate-filiform. Lower interstice zone strongly ridged; reticulate; longitudinally ridged; longitudinally sculptured; flat. Upper intersice zone flat; longitudinally sculptured; weakly verrucate. Spathe limb elliptic-lanceolate; elliptic-ovate; lanceolate; narrowy lanceolate; oblong-lanceolate; ovate-lanceolate. Staminate flower zone conical; cylindrical; globose; oblong; quadrangular; sub-quadrangular. Pistillate flower zone globose; globose-cylindric; cylindrical; oblong; oblong-cylindric; conical. Length of appendix. Appendix narrowly clavate; broadly clavate. Length of spathe tube. Width of lower interstice zone. Length of spadix. Length of lower interstice zone. Length of upper interstice zone. Length of appendix. Length of staminate flower zone. Length of peduncle at flowering. Length of appendix peduncle. Length of inflorescence. Length of lower staminode zone. Length of upper staminode zone. Length of pistillate flower zone. Length of spathe limb. Number of whorls of lower staminodes. Number of whorls of upper staminodes. Ratio length of appendix/length of stipe. Spathe limb with/without anthocyanin spots. Ratio length of appendix/length of spadix. Ratio length spadix/length inflorescence.