ARTICLES

Mediterranean Botany
ISSNe 2603-9109

EDICIONES COMPLUTENSE

http://dx.doi.org/10.5209/MBOT.59820

Arthrocaulon meridionalis (Chenopodiaceae), a new species of Mediterranean flora

Esteban Ramírez[1], Lourdes Rufo[2], Daniel Sánchez-Mata[3] & Vicenta de la Fuente [1]

Received: 9 April 2018 / Accepted: 3 October 2018 / Published online: 20 February 2019

Abstract. A new species of *Arthrocaulon* Piirainen & G. Kadereit, *A. meridionalis* is described. This diploid taxon is known from the islands of Sicily and Sardinia and from circum-Mediterranean territories (from North Africa to the Anatolian Peninsula in Turkey and as far as the Persian Gulf on the Asian continent). The distinctive macro-, micromorphological and chorological features of this taxon are given.
Keywords: *Chenopodiaceae*; *Arthrocaulon; Arthrocaulon meridionalis*; *Arthrocnemum*.

Arthrocaulon meridionalis (Chenopodiaceae), una nueva especie para la flora mediterránea

Resumen. Se describe una nueva especie de *Arthrocaulon* Piirainen & G. Kadereit, *A. meridionalis*. Conocemos este taxon diploide de las islas de Sicilia y Cerdeña y en territorios circum-mediterráneos, desde el Norte de África hasta la Península de Anatolia en Turquía alcanzando el Golfo Pérsico en el continente asiático. Se aportan los correspondientes caracteres macro-, micromorfológicos y corológicos del nuevo taxon descrito.
Palabras clave: *Chenopodiaceae*; *Arthrocaulon; Arthrocaulon meridionalis*; *Arthrocnemum.*

Introduction

Arthrocnemum was described as a new genus in the monograph on the Chenopodiaceae family published by Moquin-Tandon (1840:111). Among the basic morphological characters included by the author we highlight the following: 'hermaphrodite flowers, squamate, arranged at the branch nodes, swollen or bulging perigon, trigonous or tetragonous truncate apex, ending abruptly in a more or less straight line, finally spongy, without appendages. Stamen 1 or 2, inserted on the receptacle. Adnate style with 2 stigmas. Utricle flattened on the sides, swollen, fleshy and rolled inwards towards its upper adaxial surface; separate membranaceous pericarp. Vertical, lenticular seeds, with a persistent farinaceous perisperm. Semiannular embryo.

The morphology and taxonomy of this group of halophytes has been discussed in the scientific literature by numerous authors, e.g. Lagasca, 1817; Willkomm, 1862; Ball, 1964; Scott, 1977; Castroviejo & Coello; 1980; Pastor & Valdés, 1986; Castroviejo 1990; Castroviejo & Lago, 1992; Ball, 2003; Shepherd *et al.*, 2005; Alonso & Crespo, 2008; Kadereit *et al.*, 2006; Piirainen *et al.*, 2017.

Recently, in their in-depth study on *Arthrocnemum*, Sukhorukov & Nilova (2016) give a detailed description of its vegetative and reproductive characters such as phyllotaxis, nodes, leaves, branches and inflorescences; they do not confirm the presence of lateral staminate flowers –and therefore sterile, as proposed by Kühn (1993)–, and consider the presence of an indurated pericarp to be unfounded, as stated by Ungern-Sternberg (1866), Scott (1977), Jafri & Rateeb (1978) or Friis & Gilbert (1993). Finally, they supply novel characters: black seeds (reddish when unripe), crustaceous testa, mostly with papilla-like (conic) outgrowths located along one (embryo-bearing) side, 20-25 μm thick (in flattened cells) and up to 55 μm thick in conic cells, their outer wall bearing five to ten stalactites, cell content easily visible.

The same authors (Sukhorukov & Nilova, 2016: 237-239) indicate the need to typify the genus in a highly restrictive and conservative sense respecting the protologue and the original materials used by Moquin-Tandon in his description ['Type of the genus: not yet typified (the genus should be typified with a conserved name')]. We absolutely agree with these authors on the

[1] Departamento de Biología, Facultad de Ciencias, Universidad Autónoma de Madrid, Cantoblanco, E-28049 Madrid, Spain. Email: vicenta.fuente@uam.es
[2] Departamento de Farmacia, Facultad de Ciencias Experimentales, Universidad Francisco de Vitoria, E-28223 Pozuelo de Alarcón, Madrid, Spain.
[3] Departamento de Farmacia, Facultad de Ciencias Experimentales, Universidad Francisco de Vitoria, E-28223 Pozuelo de Alarcón, Madrid, Spain.

need to make a thorough revision of the typification of the genus *Arthrocnemum* by publishing a justified proposal for a conserved generic name with a conserved type (in prep.).

This line is overlooked in the recent work by Piirainen *et al.* (2017), where they support the old proposal of Pfeiffer who, in his Nomenclator Botanicus (1872:279 –cf. Rye & Wilson 1999:794), mentions '*Salicornia fruticulosa* L.' as a representative of the genus *Arthrocnemum*. The authors therefore publish a proposal for a new genus: *Arthrocaulon* Piirainen *et al.* which would include *Arthrocaulon macrostachyum* (Mediterranean Europe and N Africa, E Africa, SW Asia) and the one recently described from Cape Verde Islands, *Arthrocaulon franzii* (Sukhorukov & Nilova, 2016:239). They also propose the new genus *Arthroceras* (*A. subterminale*) for the west of North America.

Our review of a broad spectrum of circum-Mediterranean populations of *Arthrocaulon macrostachyum* points to the existence of contrasting genetic diversity. The tetraploid level is confirmed by Castro & Fontes (1946) and Queirós (1975) with Portuguese material, by Contandriopoulos (1968) with material from the south of France, by Castroviejo & Coello (1980) in Spain, and by Runemark (1996) with material from Greece. Ghaffari (2006:129) publishes the diploid level for this species on the coasts of the Persian Gulf ['Between Gavbandi and Kangan, Bidkhoon, 2.12.1987, Assadi & Akhani 64014 (TARI Herbarium), 2n=18'].

The phylogenetic trees presented by Piirainen *et al.* (2017) also reveal a clear separation between the Turkish and Iberian populations. Both genetic and phylogenetic data suggest a differentiation of the genus *Arthrocaulon* among the circum-Mediterranean populations. We therefore propose the new taxon *Arthrocaulon meridionalis* spec. nova to include the diploid populations distributed in southern Mediterranean halophytic habitats.

Material and Methods

Plant material

Complete fresh specimens from various Mediterranean coastal and inland territories of *Arthrocaulon* populations were collected directly from the field in different stages: spring-summer (flowers) and summer-autumn (fruits and seeds). Plant material was preserved at -20°C for subsequent analysis. Voucher specimens of the collected and analysed material are preserved in the MAF Herbarium (Faculty of Pharmacy, Complutense University, Madrid, Spain).

The morphological study of seeds and fruits was done using voucher specimens from several herbaria: MA Herbarium (Real Jardín Botánico, CSIC, Madrid, Spain), MAF Herbarium, and PAL Herbarium (Herbarium Mediterraneum Panormitanum, Palermo Botanical Garden, Sicily, Italy) and our personal collections (V. de la Fuente, UAM, Spain). A complete list of the plant material collected and the voucher specimens for this study is shown in Figure 1 and the attached appendix (Appendix 1).

Morphological and micromorphological characters

Optical microscope. The Olympus SZX10 stereomicroscope was used to take photographs of the morphological characters of interest and to take measurements of leaf lengths (mm), leaf hyaline margin width (mm), inflorescence length-width (cm), bract hyaline margin width (mm), central and lateral perianth length (mm), anther length (mm), style length-width (mm), stigma length (mm) and seed length-width (mm) (Appendix 2). The measurements were made with the program tool associated with the stereomicroscope (Olympus Stream Image Analysis Software) and the photographs with the Olympus SC30 camera, also attached with the equipment.

Scanning electronic microscopy analysis (SEM). Cross-sections of flower, fruits and seeds were cut with a sharp blade. Dry samples were fixed in situ with formyl acetic alcohol (FAA). After washing with a 0.1M phosphate buffer (pH 7.4), they were dehydrated through a graded ethanol series. Dry samples were mounted flat on the surface of conductive graphite stubs and sputtered and gold coated in a Bio-Rad SC 502 apparatus for electrical conductivity and to prevent charging under the electron beam. Samples were examined with a Hitachi S-3000N (Japan) SEM using an acceleration voltage of 20 kV and a working distance of 15 mm. The samples were analysed at room temperature.

Results

Arthrocaulon meridionalis, spec. nova
Holotypus: Italy, Sicily, between Trapani and Paceco. 'Saline di Trapani e Paceco' nature reserve, perennial halophytic communities close to Salina Chiusicella (Salicornietea fruticosae), 30STC8207, leg. June 14, 2017 by V. de la Fuente, N. Rodríguez & D. Sánchez-Mata. Type specimen preserved at MAF 176512.

Description. Perennial woody shrub up to 100 cm tall, almost always erect and less frequently prostrate. Secondary branches erect and ascending. Regular decussate ramification. Opposing amplexicaule scale-like leaves 2-3 mm long, fused at their base and to the stem forming a cyathiform structure of fleshy segments, with a scarious hyaline margin 0.3-0.5 mm wide with an acuminate apex.

Inflorescence (2.5)3.8(5.5) cm long and (0.2)0.35(0.5) cm, spicate, terminal and lateral, segmented; each fertile segmented composed of two 3-flowered cymes, decussate, immersed in the pair of opposite scale like bracts with a hyaline margin 0.4-0.65 mm wide. Cymes formed of three sessile flowers in a row, fused at the base, with the central flower arranged slightly higher than the lateral ones. Central perianth slightly longer than the two lateral sections of the perianth (1.2)1.4(1.9) / (1)1.3(1.5) mm respectively. Fleshy perianth formed of four tepals fused to the tip, which has a floral opening formed by 2 lateral orbicular flaps and two more scarious frontals. Stamens 2 with yellow anthers (0.6)0.9(1.2) mm long, apiculate at the base; superior ovary with style from 0.1 to 0.7 mm in length and 0.05 to 0.1 mm in width. 2(3) stigmas.

Fruit an utricle-like. Membranaceous pericarp partially fused to the seed. Round or ellipsoidal blackish-reddish seeds (0.8)0.9(1.1) mm long (0.6)0.65(0.8) mm wide. Sometimes surface verrucate exotesta is covered with papillae on the edge of the seed, otherwise almost smooth. Embryo curved, comma shaped. Perisperm abundant.

Distribution. This species occurs on the islands of Sicily and Sardinia and in circum-Mediterranean territories from North Africa to the Anatolian Peninsula in Turkey. Other populations not included on the map: Iran: between Gavbandi and Kangan, Bidkhoon, 2.12.1987, Assadi & Akhani 64014 (TARI Herbarium), 2n=18, Figure 1.

Figure 1. Map showing the distribution of *Arthrocaulon macrostachyum* (points) and *A. meridionalis* (stars). Numbers refer to localities and populations listed in Appendix 1.

Ecology and Phytosociology. This species grows in the most inland and xeric zones of saline habitats and can withstand high concentrations of salt. The communities undergo dry periods in summer (Brullo & Furnari, 1976). According to our field observations, it grows alongside *Sarcocornia fruticosa* (L.) A.J. Scott and *Halocnemum strobilaceum* (Pall.) M. Bieb. and forms xero-halophytic fruticose communities included in the phytosociological class *Salicornietea fruticosae* Br.-Bl. & Tüxen ex A. Bolòs 1950 (Rufo *et al.*, 2016).

In contrast, *Arthrocaulon macrostachyum* is described as a perennial woody shrub growing up to 150 cm tall, from prostrate to erect, often forming rounded mats. Secondary branches erect and ascending. Regular decussate ramification. Opposing amplexicaule scale-like leaves 2-3 mm long, fused at their base and to the stem forming a cyathiform structure of green, glaucous or reddish fleshy segments, with a scarious hyaline margin 0.3-0.4 mm wide with a slightly to very acuminate apex. Inflorescence (2.5) 2.9 (4) cm long and (0.3) 0.4 (0.5) cm wide, cylindrical, spicate, terminal and lateral, segmented; each fertile segment composed of two 3-flowered cymes, decussate, immersed in the pair of opposing scale like bracts with a hyaline margin 0.3-0.5 mm wide. Cymes formed of three sessile flowers in a row, fused at the base, and with the central flower arranged slightly higher than the lateral ones. Central perianth slightly longer than the two lateral sections of the perianth (1.9)2.1(2.4)/(1.8) 1.9 (2.3) mm respectively. Fleshy perianth formed of four tepals fused to the tip, which has a floral opening formed by two lateral orbicular flaps and two more scarious frontals. Stamens 2 with yellow anthers (0.9)1.1(1.5) mm long, apiculate at the base; superior ovary with style from 0.1 to 0.6 mm in length and 0.1 to 0.2 mm in width. 2(3) stigmas. Fruit an utricle-like. Membranaceous pericarp partially fused to the seed. Vertical, round or ellipsoidal, reddish-black seeds (0.9)1.1(1.25) mm long (0.7)0.8(0.95) mm wide. Sometimes surface verrucose exotesta is covered with papillae on the edge of the seed, otherwise almost smooth. Embryo curved, comma shaped. Perisperm abundant. *Arthrocaulon macrostachyum* is known from the Mediterranean biogeographical region, western Mediterranean subregion: Valencian-Provençale-Balearic, Central Iberian Mediterranean, Murcian-Almeriese, Betic and Andalusian-Lusitanian coastal biogeographical provinces (Portugal and Spain); Eastern Mediterranean subregion: Graeco-Aegean and Cilicio-Phoenician biogeographical provinces; Eurosiberian region, Alpino-Caucasian subregion: Apennino-Balkan province (Padanian sector) (Rivas-Martínez *et al.*, 2004, 2014) (Figure 1). Other populations not included in Figure 1 are from the Canary Islands (GenBank number

KU975176). *Arthrocaulon macrostachyum* occurs in salt marshes on the Atlantic and Mediterranean coasts in mid– and high-intertidal areas, occupying territories that are only occasionally flooded by tides, and in saline depressions where it is not usually reached by seawater. It can also be found far from the coast in endorreic lakes derived from Tertiary materials, and even in canals in salt works. It usually grows on saline sandy to clayey gypsiferous soils where it may commonly be accompanied by *Sarcocornia* and *Salicornia* species (*Salicornietea fruticosae* phytosociological class) (Rufo *et al.*, 2016).

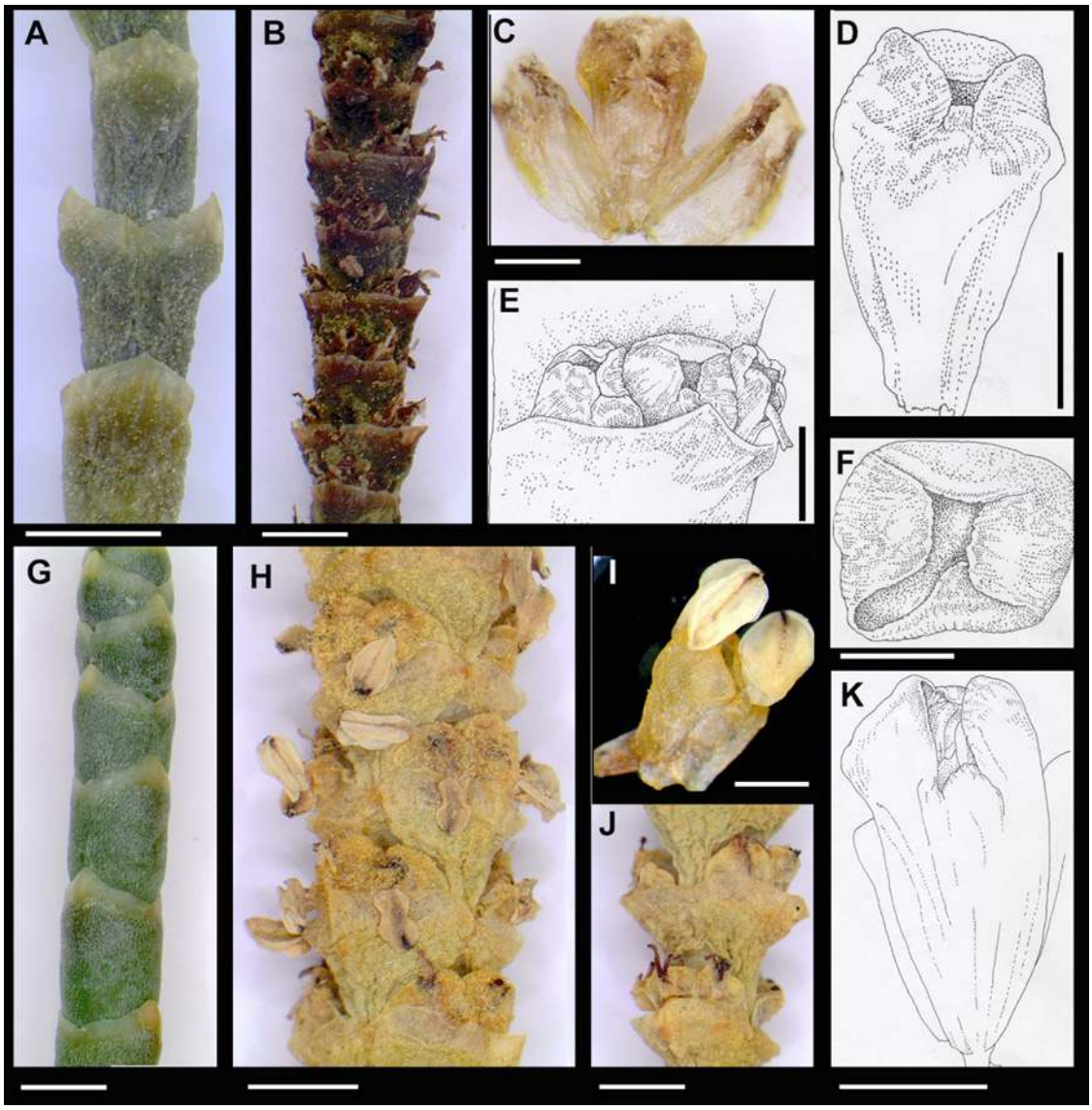

Figure 2. *Arthrocaulon meridionalis* (A-F) and *A. macrostachyum* (G-K). A, Sterile branch showing the oppossite amplexicaule leaves with a scarious hyaline margin with an acuminate apex. Scale bar: 2 mm; B,Inflorescence. Scale bar: 2 mm; C, Three sessile flowers of a cyme, the central one slightly bigger than the lateral ones. Scale bar: 500 µm; D, Detail of the perianth of a flower. Scale bar: 500 µm; E, Detail of a three flowered cyme. Scale bar: 1 mm; F, Detail of the opening of the perianth with the four flaps. Scale bar: 500 µm; G, Sterile branch showing the oppossite amplexicaule leaves with a scarious hyaline margin with an acuminate apex. Scale bar: 2 mm; H, Inflorescence. Scale bar: 2 mm; I, Perianth of a flower showing two exerted stamens. Scale bar: 2 mm; J, Detail of an inflorescence with flowers with exerted styles. Scale bar: 1 mm; K, Detail of a perianth of a flower. Scale bar: 1 mm.

Discussion

Arthrocaulon macrostachyum (2n:36) differs from *Arthrocaulon meridionalis* (2n:18) in both, its ploidy level and the different morphological characteristics of its stems, leaves, flowers and seeds, as shown in Figure 2, 3 and Appendix 2. The main differences can be summarised in the following morphological characters:

Inflorescence size. In general terms, the size of the inflorescence was found to be shorter and wider in the Iberian populations (2.5)2.9(4)/(0.3)0.4(0.5) mm long/width than in the Sicilian and Sardinian populations, which are characterized by slightly longer and thinner inflorescences (2.5)3.8(5.5)/(0.2)0.35(0.5) mm long/width.

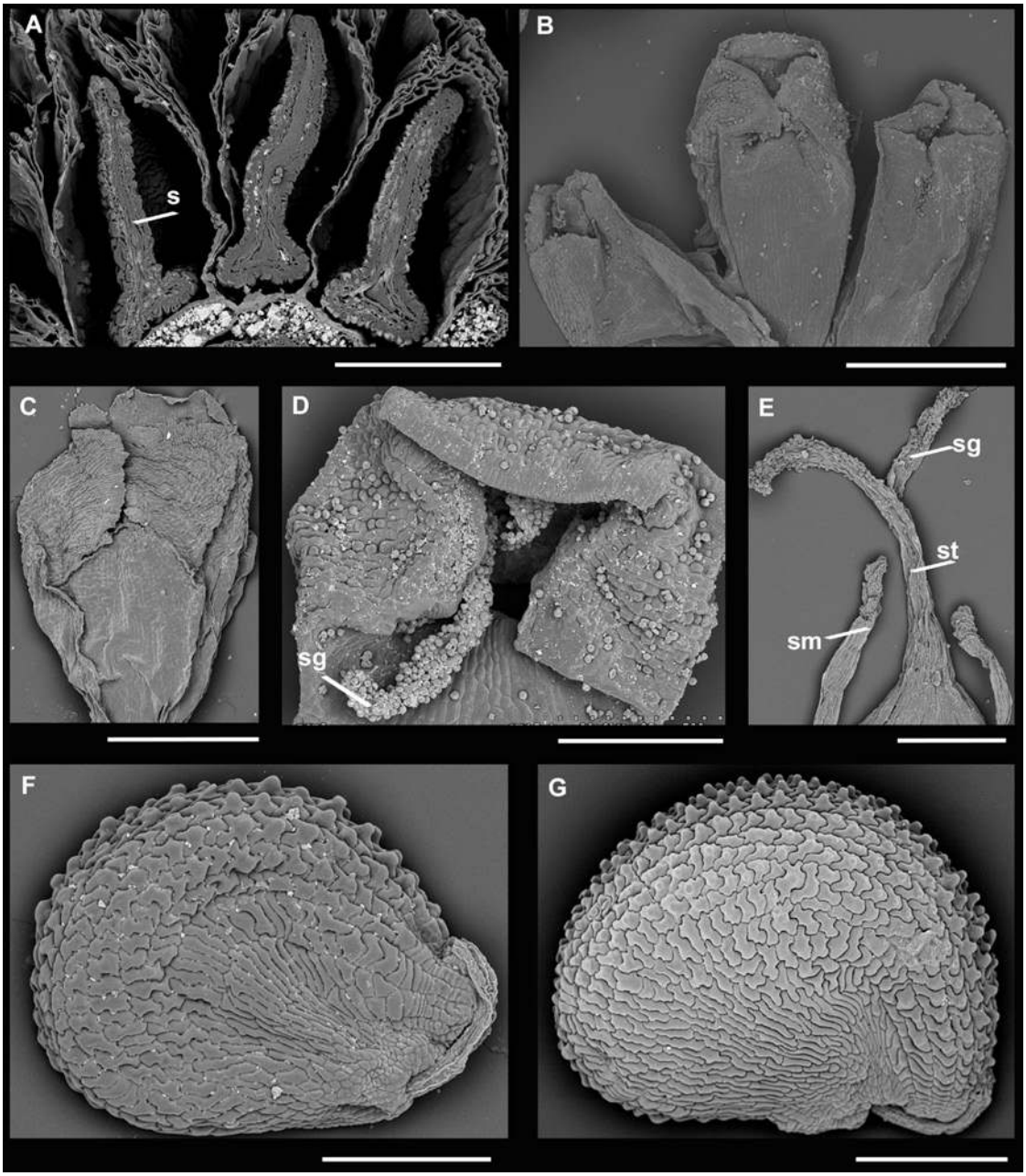

Figure 3. Representative SEM images. A) Cross section of a three flowered cyme of *A. macrostachyum*, s: seed. Scale bar: 500 µm; B) Three sessile flowers of a cyme of *A. meridionalis*. Note the central flower slightly bigger than the lateral ones. Scale bar: 1 mm; C) A fleshy perianth of a flower of *A. macrostachyum*. Scale bar: 1 mm; D) Opening of the perianth of a flower showing the four flaps of *A. meridionalis*, sg: stigma. Scale bar: 500 µm; E) Style and two stigmas with the two stamens of a flower of *A. meridionalis*, sg: stigma, st: style, sm: stamen. Scale bar: 500 µm; F) Seed of *A. meridionalis*. Scale bar: 300 µm; G) Seed of *A. macrostachyum*. Scale bar: 500 µm.

Bract hyaline margin. The scarious margin of the bracts is slightly thinner in the Iberian populations of *A. macrostachyum* compared to those from Sicily and Sardinia: 0.3-0.5 mm wide and 0.4-0.65 mm wide respectively.

Perianth. The central flower is slightly larger than the lateral ones in both species; however, the perianth in the Iberian populations ((1.9)2.1(2.4) mm central perianth and (1.8)1.9(2.3) in both lateral perianth sections) has been observed to be longer than in the Italian populations ((1.2)1.4(1.9) mm central perianth and (1)1.3(1.5) in both lateral perianth sections).

Anthers. The anthers of *A. macrostachyum* (0.9)1.1(1.5) mm are generally longer than those observed in the Italian populations ((0.6)0.9(1.2) mm long).

Style. Although the styles in the individuals observed in both species have a very similar length, differences have been found in the width; the style of the Iberian populations is wider (0.1-0.2) mm than in the Sicilian and Sardinian ones (0.05-0.1) mm.

Stigmas. The stigmas of *A. meridionalis* (0.5)0.6(0.9) mm are longer than in *A. macrostachyum* (0.3)0.4(0.6) mm.

Seeds. The seeds of both species are morphologically similar and generally slightly larger and wider in the Iberian populations ((0.9)1.1(1.25) mm long and

(0.7)0.8(0.95) mm wide) compared to the Italian ones ((0.8)0.9(1.1) mm long and (0.6)0.65(0.8) wide). Amount and size of papillae in testa cells is variable in both species.

Combined use of macro-micromorphological and biogeographical features are essential to correctly delimit plant species. This type of data has already been used by several authors for other genera of Chenopodiaceae close to *Arthrocaulon* (Alonso & Crespo, 2008; Biondi *et al.,* 2013; Fuente *et al*., 2013, 2015; Rufo *et al.,* 2016). In regard to phylogenetic relationships, the molecular phylogeny was studied in depth based on the combined analysis of ETS, ITS, atpB-rbcL and matK-trnK (Piirainen *et al.*, 2017, Supplementary Material, Figure S3), in greater detail for the genus *Arthrocaulon* than the phylogeny chosen for the main document, and revealed a separation with a moderately to well-supported bootstrap (BS 83) for the Turkish populations (ETS: KU975228*, ITS: KU975175; ETS: EF433587, ITS: AY489240, matK-trnK: KU975311) compared to the Spanish and Portuguese populations, which are grouped in politomy (ETS: KU975227, ITS: KU975174, atpB-rbcL: KU975274, matK-trnK: KU975310; ITS: AY489239, atpB-rbcL: EU484419 = DQ340101; ETS: KU975229, ITS: KU975176, atpB-rbcL: KU975275, matK-trnK: KU975312). Our data for the ITS marker corroborate this separation at the molecular level and incorporate all the sequences taken from various populations in Sicily and Sardinia in the eastern block (data not showed). It is highly likely that these separations are related with the genetic and morphological differences implied by the two types of chromosome levels present in the genus.

On the other hand, individuals sequenced in the Canary Islands in the same study (Piirainen *et al.,* 2017), in which no exact location is specified within these islands, is added to the clade of *A*. *macrostachyum*. The sequences of Piirainen *et al*. 2017 for the populations of Senegal (GenBank numbers: ETS: KU975265, ITS: KU975211, atpB-rbcL: KU975300 and matK-trnK: KU975357), present a clear separation from the rest of the sequences grouped in *A*. *macrostachyum*. In a later work (Ball *et al*., 2017), the names of these sequences were transferred from *A*. *macrostachyum* to *A*. *franzii*. Thus, the sequencing of new samples in Cape Verde, Senegal and other African areas could clarify the ascription of these populations within the genus *Arthrocaulon*. In future studies it is necessary to advance in the characterization of this genus, especially focused on the phylogeny of the populations present in the African.

Acknowledgments

We would like to thank the directors and curators of the herbaria studied (B, GH, NY, MA, MAF, PA, and US) for allowing us to study the material necessary for our research. The authors would also like to thank José María (Pepe) Pizarro for the illustrative drawings in Figure 2 and Pru Brooke-Turner for the English translations and corrections. Finally, our gratitude to the reviewers of the original manuscript extended to our colleague Alexander P. Sukhorukov (Moscow) for their valuable suggestions and comments.

This investigation was done within the framework of the research projects CGL2009-11059, CGL2008-901, CTM2010-18456, supported by the Ministries of Science and Education and Science and Innovation (Spanish Government).

References

Alonso, M.A. & Crespo, M.B. 2008. Taxonomic and nomenclatural notes on South American taxa of Sarcocornia (Chenopodiaceae). Ann. Bot. Fenn. 45: 241–254.

Ball, P.W. 1964. Flora Europaea. Notulae Systematicaead Floram Europaeam spectantes: a taxonomic review of Salicornia in Europe. Feddes Repert. 69: 1–8.

Ball, P.W. 2003. 38. Chenopodiaceae Ventenat: 21. Arthrocnemum, 22. Salicornia, 23. Sarcocornia. In: Flora of North America Editorial Committee (Eds.). The Flora of North America, vol. 4. Pp. 381–387. Oxford University Press, New York.

Ball, P.W., Cornejo, X., & Kadereit, G. 2017. Mangleticornia (Amaranthaceae: Salicornioideae). A new sister for Salicornia from the pacific coast of South America. Wildenowia 47: 145–153.

Biondi, E., Casavecchia, S., Estrelles, E. & Soriano, P. 2013. Halocnemum M. Bieb. vegetation in the Mediterranean Basin. Pl. Biosyst. 147: 536–547. doi: 10.1080/11263504.2013.832709.

Brullo, S. & Furnari, F. 1976. Le associazioni vegetali degli ambienti palustri costieri della Sicilia. Not. Fitosoc. 11: 1–43.

Castro, D. de & Fontes, F.C. 1946. Primeiro contacto citológico com a flora halófita dos salgados de Sacavém. Broteria, ser. Ci. Nat. 15: 38–46.

Castroviejo, S. 1990. Sarcocornia. In: Castroviejo, S., Laínz, M., López González, G., Montserrat, P., Muñoz Garmendia, F., Paiva, J., Villar, L., (Eds.). Flora iberica: Plantas vasculares de la Península Ibérica e Islas Baleares, vol. 2. Pp. 526–531. R. Jard. Bot., CSIC, Madrid.

Castroviejo, S. & Coello, P. 1980. Datos cariológicos y taxonómicos sobre las Salicorniinae A.J. Scott ibéricas. Anales Jard. Bot. Madrid 37: 41–73.

Castroviejo, S. & Lago, E. 1992. Datos acerca de la hibridación en el género Sarcocornia (Chenopodiaceae). An. Jard. Bot. Madrid 50(2): 163–170.

Contandriopoulos, J. 1968. A propos des nombres chromosomiques des Salicornia de la región Méditerranéenne. Bull. Mus. D'Hist. Nat. Mars. 28: 45–52.

Friis, I. & Gilbert, M.G. 1993 Chenopodiaceae. In: Thulin, M. (Ed.). Flora of Somalia, 1. Pp. 127–140. London: Royal Botanical Gardens Kew.

Fuente, V., Oggerin, M., Rufo, L., Ortúñez, E., Sánchez–Mata, D. & Amils, R. 2013. A micromorphological and phylogenetic study of Sarcocornia A.J. Scott (Chenopodiaceae) on the Iberian Peninsula. Plant Biosystems 147: 158–173. doi: 10.1080/11263504.2012.752414.

Fuente, V., Rufo, L., Rodríguez, N., Sánchez–Mata, D. & Amils, R. 2015. A study of Sarcocornia A.J. Scott (Chenopodiaceae) from Western Mediterranean Europe. Plant Biosystems. 150: 343–356. doi: 10.1080/11263504.2015.1022239.

Ghaffari, S.M., Saydrasi, L., Ebrahimzadeh, H. & Akhani, H. 2006. Chromosome numbers and karyotype analyses of species of subfamily Salicornioideae (Chenopodiaceae) from Iran. Iran. J. Bot. 12(2): 128–135.

Jafri, S.M.H. & Rateeb, F B. 1978. Chenopodiaceae. In Jafri, S.M.H. & El–Gadi, A. (Eds.) Flora of Libya, 58. Pp. 1–109. Al Faatch Univ., Tripoli.

Kadereit, G., Mucina, L. & Freitag, H. 2006. Phylogeny of Salicornioideae (Chenopodiaceae): diversification, biogeography, and evolutionary trends in leaf and flower morphology. Taxon 55: 617–642.

Kühn, U. (with additions by V. Bittrich, R. Carolin, H. Freitag, I. C. Hedge, P. Uotila, and P. G. Wilson). 1993. Chenopodiaceae. In Kubitzki, K., Rohwer, J.G. & Bittrich (Eds.). The families and genera of vascular plants, 2: Flowering Plants, Dicotyledons: Magnoliid, Hamamelid and Caryophyllid families. Pp. 253–281. Springer, New York.

Lagasca, M. 1817. Memoria sobre las plantas barrilleras de España. Imprenta Real, Madrid.

Moquin-Tandon, A. 1840. Chenopodearum monographica enumeratio. Parisiis [Paris]: apud P.-J. Loss.

Pastor, J. & Valdés, B. 1986. Números cromosómicos para la flora española, 485–490. Lagascalia 14: 297–301.

Pfeiffer, L.K.G. 1872. Nomenclator botanicus, vol. 1, part 1, division 4. Theodor Fisher, Kassel.

Piirainen, M., Liebisch, O. & Kadereit, G. 2017. Phylogeny, biogeography, systematics and taxonomy of Salicornioideae (Amaranthaceae/Chenopodiaceae). A Cosmopolitan, highly specialized hygrohalophyte lineage dating back to the Oligocene. Taxon 66(1): 109–132. doi.org/10.12705/661.6.

Queirós, M. 1975. Contribuçao para o conhecimiento dos Spermatophyta de Portugal. X. Chenopodiaceae. Bol. Soc. Brot., sér. 2, 49: 121–142.

Rivas-Martínez, S., Penas, A. & Díaz, T.E. 2004. Biogeographical Map of Europe. Scale 1:6.000.000. Serv. Cartogr., Univ. León, León.

Rivas-Martínez, S., Penas, A., Díaz González, T.E., Río, S. del, Cantó, P., Herrero, L., Pinto Gomes, C. & Costa, J.C. 2014. Biogeography of Spain and Portugal. Preliminary typological sinopsis. Int. J. Geobot. Res. 4: 1–64. doi: 10.5616/ijgr140001.

Rufo, L., Fuente, V. de la & Sánchez-Mata, D. 2016. Sarcocornia plant communities of the Iberian Peninsula and Balearic Islands. Phytocoenologia 46(4): 383–396. doi: 10.1127/phyto/2016/0113.

Runemark, H. 1996. Mediterranean chromosome number reports (590–670). Fl. Med. 6: 223–243.

Rye, B.L. & Wilson P.G. 1999. Publication details for Pfeiffer's Nomenclator botanicus. Taxon 48(4): 793–795.

Scott, A.J. 1977. Reinstatement and revision of Salicorniaceae J. Agardh (Caryophyllales). Bot. J. Linn. Soc. 75(4): 357–374.

Sukhorukov, A.P. & Nilova, M.V. 2016. A new species of Arthrocnemum (Salicornioideae: Chenopodiaceae-Amaranthaceae) from West Africa, with a revised characterization of the genus. Bot. Lett. 163(3): 237–250.

Shepherd, K.A., Macfarlane, T.D. & Colmer, T.D. 2005. Morphology, anatomy and histochemistry of Salicornioideae (Chenopodiaceae) fruits and seeds. Ann. Bot. (London) 95: 917–933. doi:10.1093/aob/mci101.

Ungern-Sternberg, F. 1866. Versuch einer Systematik der Salicornieen [An attempt of the Salicornieae revision]. E.J. Karow, Dorpat.

Willkomm, M. 1862. Chenopodiaceae Lindl. In: Willkomm, M. & Lange, J. (Eds.). Prodromus Florae Hispanicae, vol 1: 255–275. Stuttgart.

Appendix 1. Studied specimens.

Arthrocaulon macrostachyum (sub *Salicornia macrostachya* or *Arthrocnemum macrostachyum*)

1. *Holotypus*: Italy: Des environs de Venice, Malamocco, s.d., Moricand s.n. (G barcode G 00177362); 2. Spain: Alicante, Villena, Las Virtudes, 02.09.2008, 30SXH8076, *V. de la Fuente, L. Rufo & N. Rodríguez*; 3. Spain: Alicante, San Felipe Neri, El Hondo, 29.08.2008, 30SXH9327, *V. de la Fuente, L. Rufo & N. Rodríguez*; 4. Spain: Alicante, Santa Pola, Playa Lisa, 29.08.2008, 30SYH0827, *V. de la Fuente*; 5. Spain: Alicante, Marismas Santa Pola, 28.07.2006, 30SYH0928, *V. de la Fuente, N. Rodríguez, L. Rufo & R. Amils*; 6. Spain: Valencia, Sagunto, Urbanización Corinto, 25.08.2009, 30SYJ4197, *V. de la Fuente*; 7. Spain: Cádiz, Sanlúcar de Barrameda, Guadalquivir marsh, 09.07.2008, 29SQA3883, *V. de la Fuente, L. Rufo & N. Rodríguez*; 8. Spain: Toledo, Lillo, Laguna de Longar, 26.05.2009, 30SVK7495, *V. de la Fuente, N. Rodríguez, L. Rufo & R. Amils*; 9. Spain: Toledo, Villasequilla de Yepes, 26.05.2009, 30SVK3814, *V. de la Fuente, N. Rodríguez, L. Rufo & R. Amils*; 10. Spain: Zaragoza, Belchite, El Planerón, 19.01.2017, 30TXL9782, *V. de la Fuente, L. Rufo, D. Sánchez-Mata & I. Sánchez*; 11. Spain: Huelva, Odiel marsh, 26.09.2005, 29SPB8024, *V. de la Fuente, L. Rufo, N. Rodriguez & R. Amils*; 12. Spain: Huelva, Río Tinto, Moguer, 06.05.2004, 29SPB9028, *V. de la Fuente, N. Rodríguez, L. Rufo & R. Amils*; 13. Spain: Huelva, Marismas del Río Tinto, Monumento a Colón, 31.05.2005, 29SPB8220, *V. de la Fuente, L. Rufo, N. Rodriguez & R. Amils*; 14. Portugal: Coímbra, Figueira da Foz, Rio Mondego, 24.01.2017, 29TNE1144, *V. de la Fuente, L. Rufo, D. Sánchez-Mata & I. Sánchez*; 15. Spain: Murcia, San Pedro del Pinatar, Salinas de Cotorillo, 22.09.2009, 30SXG9692, *V. de la Fuente, L. Rufo & N. Rodríguez*; 16. Spain: Almería, Pozo del Esparto, 24.08.2016, 30SXG1734, *D. Sánchez-Mata*; 17. Spain: Almería, Vera, Salar de los Canos, 24.08.2016, 30SXG0621, *D. Sánchez-Mata*; 18. Spain: Almería, Parque natural del Cabo de Gata-Níjar, 21.08.2016, 30SWF8880, *D. Sánchez Mata*; 19. Spain: Huelva, Río Piedras marsh, El Rompido, 03.10.2007, 29SPB6122, *V. de la Fuente, L. Rufo & N. Rodríguez*; 20. Spain: Huelva, San Juan del Puerto, 03.10.2007, 29SPB9230, *V. de la Fuente, L. Rufo & N. Rodríguez*; 21. Spain: Huelva, Río Tinto marsh, La Rábida, 03.10.2007, 29SPB8320, *V. de la Fuente, L. Rufo & N. Rodríguez*; 22. Spain: Huelva, Ayamonte, Estero de la Nao, 19.09.2007, 29SPB4122, *V. de la Fuente, L. Rufo & N. Rodríguez*; 23. Spain: Toledo, Huerta de Valdecarábanos, MAF 109401; 24. Spain: Madrid, Villaconejos-Titulcia, Sulquisa, 10.11.2017, 30TVK5337, *V. de la Fuente, L. Rufo, D. Sánchez-Mata, I. Sánchez, E. Ramírez*; 25. Spain: Castellón, Torreblanca, Parque Natural Cabanes, 28.09.2009, 31TBE6454, *V. de la Fuente*; 26. Spain: Huelva, Doñana, Gudalquivir marsh, 09.07.2007, 29SQA3388, *V. de la Fuente, L. Rufo & N. Rodríguez*; 27. Spain: Alicante, Calpe, Laguna de Ifach, 28.08.2015, 31SBC4579, *V. de la Fuente*; 28. Spain: Tarragona, Delta del Ebro, GenBank n.: AY489239; 29. Portugal: Algarve, Alvor lagoon, Portimao,GenBank number: KU975175; 30. France: Provence-Alpes-Côte d'azur, Bouches-du-Rhone, Marseille, MAF 97156; 31. France: Occitania, Hérault, Palavas, 30.11.2012, 31TEJ7620, *V. de la Fuente, L. Rufo & N. Rodríguez*; 32. Morocco: Tétouan, Asilah, Oued Rharifa, MAF 134517; 33. France: Saintes Maries de la Mer, Camargue, GenBank number: AY996260; 34. Greece: Kiklades, Naxos, S. of the town, Runemark. 2n=36;

Other populations not included on the map: Spain: Canary Islands, GenBank number: KU975176.

Arthrocaulon meridionalis

35. *Holotypus*: Italy, Sicily, between Trapani and Paceco. 'Saline di Trapani e Paceco' nature reserve, perennial halophytic communities close to Salina Chiusicella (Salicornietea fruticosae), 30STC8207, leg. June 14, 2017 by *V. de la Fuente, N. Rodríguez & D. Sánchez-Mata* (MAF 176512); 36. Italy: Sicily, Palermo, Cinisi, Playa de Cinisi, 15.06.2017, 33SUC3225, *V. Fuente, N. Rodríguez & D. Sánchez-Mata*; 37. Italy: Sicily, Siracusa, Riserva Naturale Orientata Oasi Faunistica di Vendicari, 17.06.2013 and 16.06.2017, 33SWA0974, *V. de la Fuente, N. Rodríguez & D. Sánchez-Mata*; 38. Italy: Sardinia, Sta. Gilla, Cagliari, 25.06.2009, 32SNJ0841, *V. de la Fuente*; 39. Italy: Sardinia, Isle Sant'Antioco, Is Pruinis-Playa, 29.11.2012, 32SMJ5321, *V. de la Fuente, L. Rufo, N. Rodríguez & R. Amils*; 40. Spain: Melilla, dunes humides de la Bocana, 24.11.1932, *Sennen & Mauricio*, BC 141886); 41. Turkey: Adana, C5 Seyhan, Akyatan, GenBank number: KU975175; 42. Turkey: SE Adana, Seyhan, GenBank number: AY489240;

Other populations not included on the map: Iran: between Gavbandi and Kangan, Bidkhoon, 2.12.1987, *Assadi & Akhani* 64014 (TARI). 2n=18.

Collection of morphological characters of the three species of *Arthrocaulon*: *A. meridionalis*, *A. macrostachyum* and *A. franzii*.

Characters/Taxon	*A. meridionalis*	*A. macrostachyum*	*A. franzii*
Leaf length (mm)	2-3	2-3	5
Leaf hyaline margin width (mm)	0.3-0.5	0.3-0.4	no data
Inflorescence length/width (cm)	(2.5) 3.8 (5.5) / (0.2) 0.35 (0.5)	(2.5) 2.9 (4) / (0.3) 0.4 (0.5)	Maximum 10 / (width no data)
Flowers	3 in a cyme, fused at the base, central slightly larger and arranged higher than lateral flowers	3 in a cyme, free, central slightly larger and arranged higher than lateral flowers	3 in a cyme, free, central slightly larger than the lateral
Bract hyaline margin width (mm)	0.4-0.65	0.3-0.5	no data
Perianth (no. segments-no. lobes)	4-4	4-4	(4 central, 3 lateral) flowers and without terminal lobes
Perianth length central/lateral(mm)	(1.2) 1.4 (1.9)/(1) 1.3 (1.5)	(1.9) 2.1 (2.4)/(1.8) 1.9 (2.3)	1.3-1.7
Number of stamens	2	2	1-2
Anther length (mm)	(0.6) 0.9 (1.2)	(0.9) 1.1 (1.5)	0.8-1.0
Style length (mm)	(0.1) 0.3 (0.7)	(0.1) 0.35 (0.6)	1.0-1.5
Style width (mm)	0.05-0.1	0.1-0.2	no data
Number of stigmas	2-3	2-3	2
Stigma length (mm)	(0.5) 0.6 (0.9)	(0.3) 0.4 (0.6)	± 1
Seed length/width (mm)	(0.8) 0.9 (1.1) / (0.6) 0.65 (0.8)	(0.9) 1.1 (1.25) / (0.7) 0.8 (0.95)	(1-1.3) / (0.7-0.8)
References	Own observations	Own observations and Castroviejo 1990	Shukhorukov & Nilova, 2016