Iheringia
Série Botânica
ISSN ON-LINE 2446-8231

Jardim Botânico de Porto Alegre
Museu de Ciências Naturais

Karyotype inconsistencies in the taxonomy of the genus *Oxalis* (Oxalidaceae)

Amália Ibiapino Moura[1], Ykaro Richard Oliveira[2,*], Paulo Henrique da Silva[2], Yennifer Mata-Sucre[1], Reginaldo de Carvalho[3], Margareth Ferreira de Sales[3], Maria Carolina de Abreu[4]

[1]Programa de Pós-Graduação em Biologia Vegetal. Universidade Federal do Pernambuco (UFPE). Laboratório de Evolução e Citogenética Vegetal. CEP: 50670-901, Recife, Pernambuco, Brasil.
[2]Secretaria do Estado da Educação (SEDUC). CEP: 64600-000, Picos, Piauí, Brasil.
[3]Programa de Pós-Graduação em Botânica. Universidade Federal Rural de Pernambuco (UFRPE). CEP 52171-900, Recife, Pernambuco, Brasil.
[4]Laboratório de Botânica. Universidade Federal do Piauí (UFPI), Campus Senador Helvídio Nunes de Barros. CEP: 64600-000, Picos, Piauí, Brasil.
*Autor para correspondência: ykr-oliveira@hotmail.com

Recebido em 05.X.2018
Aceito em 16.I.2020
DOI 10.21826/2446-82312020v75e2020003

ABSTRACT – The family Oxalidaceae consists of six genera, of which *Oxalis* is the most representative. This genus is subdivided into four subgenera, and its species present great morphological variation, which makes it difficult to identify them. The aim of this study was to make a survey of scientific publications which presented chromosome numbers of species of *Oxalis*, and to compare the chromosome numbers to the taxonomic classification proposed by Alicia Lourteig. Published chromosome counts were found for 112 species. We infered that there is apparently no relation between the chromosome numbers of the species of *Oxalis* and the taxonomic classification proposed by Lourteig, as species belonging to a same subgenus did not present a coherent pattern in chromosome numbers.

Keywords: chromosome number, cytogenetics, polyploidy

RESUMO – **Inconsistências cariotípicas na taxonomia do gênero Oxalis (Oxalidaceae)**. A família Oxalidaceae é constituída por seis gêneros no qual *Oxalis* é o mais representativo. Esse gênero é subdividido em quatro subgêneros e suas espécies apresentam grande variação nas características morfológicas, o que dificulta a identificação taxonômica das mesmas. Este trabalho teve como objetivo fazer o levantamento de artigos científicos que apresentassem o número cromossômico das espécies do gênero *Oxalis* e relacionar o número cromossômico com a classificação taxonômica proposta por Alicia Lourteig. Foram encontradas publicações evidenciando o número cromossômico de 112 espécies. A partir deste estudo podemos inferir que não há relações entre o número cromossômicos das espécies de *Oxalis* e a classificação taxonômica estabelecida por Lourteig, já que espécies pertencentes ao mesmo subgênero não apresentaram padrão no número cromossômico.

Palavras-chave: citogenética, número cromossômico, poliploidia

INTRODUCTION

The family Oxalidaceae R.Brown is included in the order Oxalidales and includes six genera and approximately 770 species distributed mainly in tropical regions (Judd 2009, Stevens 2001). *Biophytum* DC. and *Oxalis* L. are native in Brazil and *Averrhoa* L. is cultivated in the country (Fiaschi & Conceição 2005, Abreu *et al.* 2013). *Oxalis* is cosmopolitan and presents about 500 species and can be divided into four subgenera: *Monoxalis* (Small) Lourt., *Trifidus* Lourt., *Thamnoxys* (Endl.) Reiche and *Oxalis*. It is believed that South America and Africa are the centers of dispersion and probably of origin of this genus (Knuth, 1930 Denton 1973, Lourteig 1994, 2000, Azkue 2000).

Although this subdivision facilitates the complex and confusing taxonomy of the South American species of *Oxalis*, establishing a relationship among the sections is still difficult due to the high morphological variation and phenotypic plasticity (Lourteig 1994, 2000, Azkue 2000, Emshwiller & Doyle 2002). Phylogenetic studies of *Oxalis* are scarce and the relationships among the subgenera and sections are unclear (Abreu *et al.* 2012). In Brazil, some regional works related to the taxonomy of the group can be highlighted, such as the one performed in the Atlantic Forest, in which 63 species are cited (Abreu & Fiaschi 2009); nine species were recorded in the state of Pernambuco (Abreu 2007); four species were recorded by Souza & Bianchini (2000) in São Paulo and 23 species by Fiaschi & Conceição (2005) and records of 42 species in the state of Santa Catarina (Lourteig 1983).

Probably the most comprehensive taxonomic studies of the genus were performed by Knuth (1930) and Salter

(1944) for South African species and Lourteig (1994, 2000) for South American ones. However, this genus presents many difficulties of identification, mainly because of the use of morphological characteristics that are not very clear (Abreu 2007). For example, *Oxalis* stem has a variable morphology in tubers, rhizomes and true bulbs (Vaio *et al.* 2013). Therefore, cytotaxonomy represents an important tool for the determination of the taxonomic positioning of taxa (Stace 1989). Studies on the cytotaxonomy of the genus point to a wide variation in chromosome number and karyotype. It is a multibasic genus $x = 5, 6, 7, 8, 9$ and 11, with diverse morphology, acrocentric, submetacentric, telocentric and metacentric chromosomes (Azkue 2000, Azkue & Martinez 1983, 1984, 1988, 1990).

Therefore, the aim of this work was to analyze scientific studies in which the number of chromosomes of the species belonging to the genus *Oxalis* were evidenced to establish relations between the chromosome number of these species and the taxonomic classification proposed by Lourteig (1994, 2000).

MATERIAL AND METHODS

For the development of this article, studies that approached cytotaxonomic aspects of species belonging to the genus *Oxalis* were investigated. They were obtained from databases, such as: SciELO (Scientific Eletronic Library Online), ScienceDirect and Web CAPES, using the keywords: *Oxalis*, *Thamnoxys*, chromosome number, cytotaxonomy, Oxalidaceae and Oxalidales. In addition, an indirect search was performed, observing the bibliographic citations, in which mainly the oldest references were requested by the interchange service among libraries. The collected information was organized into a Microsoft Excel 2010 spreadsheet, following the order, subgenus, section, species, number *n*, number 2*n* and author. Information on subgenera and sections was obtained in Lourteig (1994, 2000).

In order to test for relationships between the chromosome numbers (CN hereafter) and the taxonomic classification by Lourteig (1994, 2000), the following data were calculated for the whole dataset and for each section: mean CN and boxplots, coefficient of variation of CN (CVCN) and CN profiles by linear regression. ANOVA was used to test statistical differences in CN among considered groups, after verification of the normal distribution of the data (Levene statistics). If data failed the normal distribution test then a non-parametric test (U Mann–Whitney/H Kruskal–Wallis) was used instead.

RESULTS AND DISCUSSION

Forty-seven studies reagarding the cytogenetics of the genus *Oxalis* were selected. It was possible to identify the most adopted method by the authors for the preparation of the plant samples and observation of chromosome numbers. Most of the papers stated that plant samples were grown in greenhouses and root tips or floral buds were used for obtaining the samples for the analysis of the chromosomes.

Regarding the methodology used in these researches, the samples were pretreated with 0.2% or 0.5% colchicine from 4 to 24 hours or with 8-hydroxyquinoline for 24 hours. Carnoy (ethanol: acetic acid 3: 1) was used as fixative for 24 hours at room temperature. The samples were digested in enzymatic solutions of 2% pectinase and 20% cellulase at 37 °C for 45 minutes, and were crushed in slide and then immersed in liquid nitrogen to remove of the glass slide. After air-drying, the material was stained, generally in 2% Giemsa. The root tips were also stained with 2% acetic orcein. In this case, after being removed from the fixative, the root tips were placed in test tubes with acetic orcein and HCL, then the mixture was heated and after cooling, the material was placed on the slide and crushed. These techniques allowed the chromosomes to be visualized, counted and photographed under an optical microscope.

Among the 500 species of *Oxalis*, 112 were recorded in this work as having their chromosomal numbers published (Tab. 1). Numbers $n = 5, 6, 7, 9, 11, 12, 14$ and 17 were observed from this data. In this study, species with $n = 7$ are the majority, with 36 representatives. The numbers $2n = 10, 12, 14, 16, 18, 20, 21, 22, 24, 28, 30, 32, 35, 36, 40, 42, 44, 64$ and 72 were recorded; where the mean CN for the full dataset is $2n = 21.73 \pm 12.56$ SD and mode $2n = 14$ with 32 species and $2n = 12$ with 26 species, resulting in a positive skew of data distribution (sk = 0.215). Most of the data (39–40% of the dataset) were concentrated in seven sections: *Articulatae*, *Cernuae*, *Corniculatae*, *Ionoxalis* and *Lotoideae* (subgroup *Oxalis*) and *Polymorphae* and *Thamnoxys* (subgroup *Thamnoxys*) (Table 2). CNs are apparently distributed in different proportions between these sections and this difference is supported by ANOVA statistic ($F = 2.300$, $DF = 20$, $p < 0.01$) and linear regresion ($R = 0.06$, $DF = 125$, $p = 0.946$) (Fig.1), differing significantly among all the 21 considered sections by Lourteig. The variation of the data for each section is shown in Table 2.

According to Bedini *et al.* (2012) and this work, the single chromosome numbers and the quantitative studies of CN variation are useful for characterization (*e.g.* distinction) of lineages at the order, family, and, in some instances, the genus level. Regarding the section that each species belonged and its chromosome number, the subgenus *Oxalis* was registered by species belonging to the sections: *Alpinae* Reiche, *Articulatae* Knuth, *Carnosae* Reiche, *Cernuae* Knuth, *Corniculatae* DC., *Giganteae* Lourt., *Herrerae* Knuth, *Ionoxalis* (Small) Knuth, *Lotoideae* Lourt., *Ortgieseae* Knuth, *Oxalis* Lourt., *Palmatifoliae* Reiche, *Pseudobulbosae* Norl., *Rhombifoliae* (Knuth) Lourt., *Ripariae* Lourt., *Roseae* (Reiche) Knuth.

The sect. *Articulatae* includes five species and all had their chromosome numbers reported, with $n = 6, 7$ and $2n = 12, 14, 42$. The value $2n = 14$ was found in all species, whereas $2n = 42$ was found only in *Oxalis articulatae*. This section is distinguished by the presence of vertically enlarged xylopodium, obcordate leaflets and leaflets and

Table 1. Chromosome numbers of species of the genus *Oxalis* addressed in the research.

Taxa	*n*	2*n*	Authorship
Subg. *Oxalis* sect. *Alpinae* Reiche			
Oxalis squamata Zucc.	9		Azkue (2000)
Oxalis valdiviensis Barnéoud	9		Warburg (1938), Marks (1956), Naranjo *et al.*(1982), Azkue (2000)
Subg. *Oxalis* sect. *Articulatae* Knuth			
Oxalis articulata Savigny	7	14	Naranjo *et al.* (1982), Heitz (1927)
		14	Azkue (2000), Vaio *et al.* (2016), Warburg (1938)
Oxalis articulata Savigny		42	Marks (1956)
	7	42	Heitz (1927), Warburg (1938)
Oxalis articulata subsp. *rubra* (A. St.-Hil.) Lourteig		14	Azkue (2000), Vaio *et al.* (2016)
Oxalis floribunda Lehm.		14	Azkue (2000), Azkue & Martinez (1988)
Oxalis floribunda subsp. *ostenii* (Arechav.) Lourteig	7		Naranjo *et al.* (1982)
Oxalis lasiopetala Zucc.	6	12	Naranjo *et al.* (1982)
		14	Azkue (2000), Vaio *et al.* (2016)
Oxalis linarantha Lourteig		14	Vaio *et al.* (2016)
Oxalis monticola Arechav.		14	Azkue (2000), Vaio *et al.* (2016)
Subg. *Oxalis* sect. *Carnosae* Reiche			
Oxalis pachyrrhiza Wedd.		18	Azkue (2000)
Oxalis tortuosa Lindl.	7	28	Marks (1956)
Subg. *Oxalis* sect. *Cernuae* Knuth			
Oxalis asinina Jacq.		28	Heitz (1927), Warburg (1938)
Oxalis bowiei Herb. *ex* Lindl.	7	28, 42	Marks (1956)
		28	Warburg (1938)
Oxalis bupleurifolia A. St-Hil.	5	10	Heitz (1927), Marks (1956)
		10	Azkue & Martinez (1988), Heitz (1927)
Oxalis caprina Thunb.	5	20	Heitz (1927)
		20	Warburg (1938)
Oxalis carnosa Molina		18	Azkue (2000)
Oxalis cathara Salter	7	14	Marks (1956)
Oxalis ciliaris Jacq.	5		Marks (1956)
Oxalis cuneata Jacq.	6	12	Marks (1956)
Oxalis dentata Jacq.	7	14	Marks (1956)
Oxalis dimidiata Donn. Sm.		7	Weller & Denton (1976)
Oxalis fabifolia Jacq.	7	28	Heitz (1927), Warburg (1938)
Oxalis hirta L.		30	Marks (1956)
Oxalis hirta var. *tubiflora* Salter	7	28	Dreyer & Johmon (2000)
Oxalis imbricata Moq.		40	Marks (1956)
Oxalis incarnata L.	7	14	Marks (1956)
	7	28	Marks (1956)
Oxalis lasiandra Zucc.	7		Weller & Denton (1976)
		28	Warburg (1938)
Oxalis lespedezioides G. Don		12	Azkue & Martinez (1990)
Oxalis linearis Jacq.		12	Azkue & Martinez (1988)
Oxalis massoniana T.M. Salter	7	14	Marks (1956)
Oxalis namaquana Sond.	7	28	Marks (1956)
Oxalis pardalis Sond.	7	14	Marks (1956)
Oxalis phaseolifolia (Rusby) R. Knuth		12	Azkue (2000)
Oxalis polyphylla var. *pentaphylla* Salter.		30	Heitz (1927)
		28	Warburg (1938)
	7	28	Marks (1956)
Oxalis pes-caprae L.	7	14	Mathew (1958)
	17		Sidhu & Bir (1983)
	7	35	Yamashita (1935)
Oxalis purpurea L.	7	42	Marks (1956)
Oxalis purpurata Jacq.	7	28	Heitz (1927)
Oxalis roselata A. St.-Hil.		10	Azkue (2000)
Oxalis rusciformis J.C. Mikan		10	Azkue & Martinez (1988)
Oxalis semiloba Sond.	7	28	Dreyer & Johmon (2000)

Table 1. Cont.

Taxa	*n*	2*n*	Authorship
Oxalis smithiana Eckl. & Zeyh.	7	14	Heitz (1927)
Oxalis tenuifolia Jacq.	7	28	Heitz (1927)
Oxalis tragopoda Salter	7	14	Marks (1956)
Oxalis truncatula Jacq.	7	14	Dreyer & Johmon (2000)
	7	42	Heitz (1927)
	7	14	Heitz (1927)
Oxalis versicolor L.		30	Yamashita (1935)
		14	Warburg (1938)
	5	30	Marks (1956)
Subg. *Oxalis* sect. *Corniculatae* DC.			
Oxalis bisfracta Turcz.		36	Azkue (2000)
		12, 24, 36	Azkue (2000)
Oxalis conorrhiza Jacq.	6	12, 18	Naranjo (1982)
	6	12	Marks (1956)
		24	Rutland (1941)
	6	24	Mathew (1958)
	12		Sarkar *et al.*(1982)
Oxalis corniculata L.		44	Sidhu & Bir (1983)
	22		Roy *et al.* (1988)
		12, 16, 32	Xu *et al.* (1992)
		48	Nair & Kuriachan (2004)
Oxalis dumetorum Barnéoud		12	Azkue (2000)
Oxalis eriocarpa DC.		10	Azkue & Martinez (1984)
Oxalis niederleinii R. Knuth		10	Azkue & Martinez (1984)
	5	10	Naranjo (1982)
Oxalis refracta A. St.-Hil.	5	10	Naranjo (1982)
		10	Azkue & Martinez (1984)
Oxalis rubens Haw.		24	Murray & Lange (1999)
	6	24	Wulff (1937)
Oxalis stricta L.		24	Kapoor & Ramcharitar (1982)
	12		Mulligan (1984)
Subg. *Oxalis* sect. *Gigantea* Lourt.			
Oxalis gigantea Barnéoud		18	Azkue (2000)
Subg. *Oxalis* sect. *Herrerae* Knuth			
Oxalis peduncularis Kunth		16	Azkue & Martinez (1990)
Oxalis san-miguelii subsp. *urubambensis* (R. Knuth) Lourteig	7	14	Heitz (1927)
Oxalis teneriensis R. Knuth		16	Azkue & Martinez (1990)
Subg. *Oxalis* sect. *Ionoxalis* (Small) Knuth			
Oxalis bipartita A. St.-Hil.		42, 54	Azkue (2000)
Oxalis bipartita subsp. *pabstii* Lourteig	7	14	Naranjo (1982)
Oxalis brasiliensis G. Lodd.	7	14	Heitz (1927), Naranjo (1982)
	7	28	Yamashita (1935), Marks (1956)
Oxalis debilis Kunth		28	Azkue (2000)
	7	14	Naranjo (1982)
Oxalis debilis var. *corymbosa* (DC.) Lourt.		28	Roy *et al.* (1988)
		14	Xu *et al.* (1992)
Oxalis decaphylla Kunth		14	Weller & Denton (1976)
		14, 28	Warburg (1938)
Oxalis divergens Benth. *ex* Lindley		21	Weller & Denton (1976)
Oxalis drummondii A. Gray	7	14	Heitz (1927)
		14	Warburg (1938)
Oxalis eriolepis Wedd.		20	Marks (1956)
		12	Azkue (2000), Azkue & Martinez (1988)
Oxalis hispidula Zucc.	14	35	Naranjo (1982)
		42	Azkue (2000)
Oxalis latifolia Kunth	7	14	Heitz (1927)
		14	Diers (1961)

Table 1. Cont.

Taxa	*n*	2*n*	Authorship
Oxalis perdicaria (Molina) Bertero	14	28	Naranjo (1982)
		28	Azkue (2000)
Oxalis primavera (Rose) R. Knuth		21	Weller & Denton (1976)
Oxalis sellowiana Zucc.	7	14	Naranjo (1982)
		36	Azkue & Martinez (1983)
Oxalis tetraphylla Cav.	7	28	Mathew (1958)
		28	Weller & Denton (1976)
	7	14	Heitz (1927), Warburg (1938)
	7	56	Marks (1956)
Oxalis tetraphylla var. *mexicana* Denton		14	Weller & Denton (1976)
	7	28	Heitz (1927), Yamashita (1935)
		28	Warburg (1938)
Oxalis violacea L.	7	14	Mathew (1958)
		14	Weller & Denton (1976)
	14		Freeman & Brooks (1988)
Subg. *Oxalis* sect. *Lotoideae* Lourt.			
Oxalis andina Britton	8	16	Azkue (2000)
Oxalis integra R. Knuth		16	Azkue & Martinez (1990)
Oxalis lotoides Kunth		32	Azkue & Martinez (1990)
Oxalis medicaginea Kunth		16	Azkue & Martinez (1990)
Oxalis melilotoides Zucc.	9		Azkue (2000)
Oxalis mollissima (Rusby) R. Knuth		16	Azkue & Martinez (1990)
Oxalis spiralis Ruiz & Pav. *ex* G. Don		48	Azkue & Martinez (1990)
Oxalis tabaconasensis R. Knuth		16	Azkue & Martinez (1990)
Oxalis tuberosa Molina	7	14	Heitz (1927), Warburg (1938)
		64	Azkue & Martinez (1990)
Subg. *Oxalis* sect. *Ortgieseae* Knuth			
Oxalis ortigiesii Regel	7	14	Heitz (1927)
Subg. *Oxalis* sect. *Oxalis*			
	11	22	Nakajima (1936)
		28	Probatova & Sokolovskaya (1988)
Oxalis acetosella L.		22	Al-Bermani *et al.* (1993), Arohonka (1982), Dmitrieva (1986), Dobes (1997), Laane & Lie (1985), Love (1982), Marks (1956), Nishikawa (1982), Pashuk (1987), Plante (1995), Warburg (1938)
Oxalis griffithii Edgew. & Hook. f.		35	Matsura & Suto (1935)
Subg. *Oxalis* sect. *Palmatifoliae* Reiche			
Oxalis adenophylla Gillies *ex* Hook. & Arn.	7	28	Heitz (1927)
Oxalis enneaphylla Cav.		28	Azkue (2000)
Subg. *Oxalis* sect. *Pseudobulbosae* Norl.			
Oxalis niederleiniana Hieron. *ex* R. Knuth		22	Azkue (2000)
		28	Azkue (2000)
Oxalis triangularis A. St.-Hil.	7	14	Naranjo (1982)
		12	Brücher (1969)
Oxalis triangularis subsp. *papilionacea* (Hoffmanns. *ex* Zucc.) Lourteig		28	Azkue (2000)
Subg. *Oxalis* sect. *Rhombifoliae* (Knuth) Lourt.			
Oxalis rhombifolia Jacq.		ca. 80	Heitz (1927), Warburg (1938)
Subg. *Oxalis* sect. *Ripariae* Lourt.			
Oxalis hepatica Norlind		10	Azkue & Martinez (1984)
Oxalis sarmentosa Zucc.		10	Azkue & Martinez (1984)
Subg. *Oxalis* sect. *Roseae* (Reiche) Knuth			
	7	14	Heitz (1927)
		14	Warburg (1938)
Oxalis rosea Feuillée *ex* Jacq.	6	12	Marks (1956)
	6		Azkue (2000)
Subg. *Thamnoxys* sect. *Hedysaroideae* DC.			
Oxalis tessmannii R. Knuth		18	Azkue (2000)

Table 1. Cont.

Taxa	*n*	2*n*	Authorship
Subg. *Thamnoxys* sect. *Polymorphae* (Prog.) Lourt.			
Oxalis alstonii Lourteig		10	Azkue & Martinez (1988), Scvortzoff (2012)
Oxalis neuwiedii Zucc.		12	Azkue & Martinez (1983, 1988)
		19	Scvortzoff (2012)
Oxalis rhombeo-ovata A. St.-Hil.		14	Azkue (2000), Azkue & Martinez (1983, 1988), Warburg (1938)
	6	12	Marks (1956)
	6		Azkue (2000)
Oxalis roselata A. St.-Hil.		10	Azkue (2000)
Oxalis umbraticola A. St.-Hil.		10	Scvortzoff (2012)
Subg. *Thamnoxys* sect. *Psoraleoideae* Lourt.			
Oxalis chartacea Norlind		12	Azkue (2000)
Oxalis erosa R. Knuth		12	Azkue (2000), Azkue & Martinez (1983, 1988)
Oxalis psoraleoides Kunth	6	12	Marks (1956)
		12	Azkue (2000), Azkue & Martinez (1983, 1988), Scvortzoff (2012)
Subg. *Thamnoxys* sect. *Robustae* (Prog.) Lourt.			
Oxalis grisea A. St.-Hil. & Naudin		12	Azkue (2000), Azkue & Martinez (1983, 1988)
Oxalis juruensis Diels		12	Azkue (2000)
Oxalis praetexta Progel		10	Azkue & Martinez (1984)
Subg. *Thamnoxys* sect. *Thamnoxys* (Endl.) Progel			
Oxalis barrelieri L.		24	Azkue (2000), Azkue & Martinez (1983), Azkue & Martinez (1988)
		12	Scvortzoff (2012)
Oxalis cratensis Hook.		12	Azkue & Martinez (1988), Scvortzoff (2012)
		12	Azkue & Martinez (1983), Scvortzoff (2012)
Oxalis cytisoides C. Mart. & Zucc.		28	Roy *et al.* (1988)
		14	Xu *et al.* (1992)
Oxalis divaricata Mart. *ex* Zucc.		12	Scvortzoff (2012), Azkue & Martinez (1983)
Oxalis dombeyi A. St.-Hil.		16	Azkue (2000)
		14	Warburg (1938)
Oxalis frutescens L.		12	Azkue & Martinez (1983, 1988), Scvortzoff (2012)
Oxalis hedysarifolia Raddi		12	Scvortzoff (2012)
Oxalis renifolia R. Knuth		12	Azkue & Martinez (1988)
Oxalis sellowii Spreng.		36	Azkue & Martinez (1983, 1988)
		72	Azkue & Martinez (1988)
Oxalis sepium A. St.-Hil.		12	Azkue & Martinez (1983, 1988)
Oxalis trianae R. Knuth		36	Azkue (2000)

Information was organized following the order, subgenus, section, species, number n, number 2n and author.

sepals with *calli*. This section, according to Lourteig (2000), is morphologically related to the sect. *Alpinae*, by the presence of vertically enlarged xylopodium and broadly peciolated trifoliolate leaves. In the sect. *Alpinae* are found 25 species, but only *Oxalis squamata* and *O. valdiviensis* had their chromosomal numbers studied, with $n = 9$, different from the values revealed in *Articulatae*.

Oxalis pachyrrhiza and *O. tortuosa* were the only species of the sect. *Carnosae* that had the chromosomal number revealed, with $2n = 18$ and $2n = 28$, respectively. This section includes 15 species and can be distinguished by the following combination of caracteres: succulent and gradually deciduous stem leaving sclerified stipules, external sepals enlarged at the base and oblong-linear internal sepals. In the sect. *Cernuae*, 33 species were studied, revealing $2n = 7, 10, 12, 14, 18, 28, 30, 35, 40, 42$. The most frequent values was $2n = 14$ and $2n = 28$, which were found in 10 and 9 species, respectively. The species of this section are easily recognized by the presence of tunicate bulbs, different from the sect. *Ionoxalis*, which includes individuals with bracteated bulbs (Lourteig 2000).

In sect. *Corniculatae*, 9 species were studied, with $n = 5, 6, 12$ and $2n = 10, 12, 16, 18, 24, 32, 36, 44, 48$. The values $2n = 10, 12, 24$ were the most frequent, being found $2n = 12$ for *Oxalis conorrhiza*, *O. corniculata*, *O. dumentorum*; $2n = 10$ for *O. eriocarpa*, *O. niederleinii*, *O. refracta* and $2n = 24$ for *O. conorrhiza*, *O. corniculata*, *O. rubens*, *O. stricta*. The species that presented $2n = 10$ stand out within the sect. *Corniculatae* by the following combination of caracteres: glandular-viscous to glandular-hirsute plant with simple hairs, enlarged stem and ovoid to oblong capsule (Lourteig 2000). The specie *O. corniculata* was investigated in seven different studies and presented

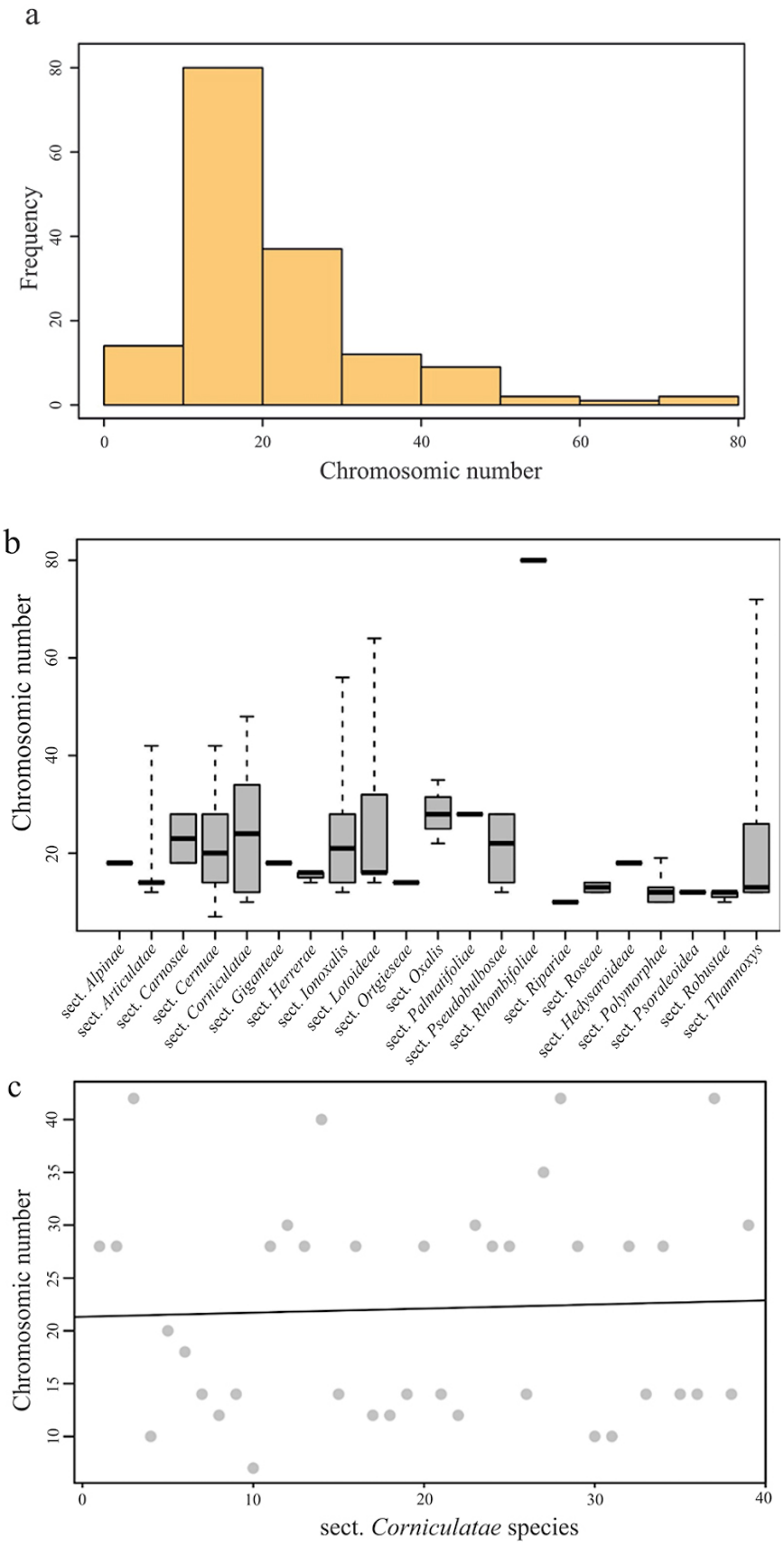

Fig. 1a-c. **a.** Histograms showing the percentage frequencies (y-axis) of 2*n* chromosome numbers (x-axis) of the species in the genus *Oxalis*; **b.** Boxplot of the chromosomic numbers (2*n*) of the different sections between the genus *Oxalis,*showing the non-relations between the chromosome number; **c.** Regresion graphs of the species of section *Corniculatae* of the subgroup *Oxalis*, showing a non-satistical relations between the cromosome number and the species of this section.

Table 2. Chromosome numbers variation among subgroups and sections of the *Oxalis* genus. N = number of species, SD = standard desviation

Subgroups of *Oxalis* genus	N	Mean	SD	CVCN	Mode
Subg. *Oxalis*					
sect. *Alpinae* Reiche	2	18	0.000	0	18
sect. *Articulatae* Knuth	8	17.25	10.024	0.581	14
sect. *Carnosae* Reiche	2	23	7.071	0.307	18
sect. *Cernuae* Knuth	39	22.1	10.256	0.464	28
sect. *Corniculatae* DC.	16	23.75	12.390	0.521	24
sect. *Gigantea* Lourt.	1	18	-	-	18
sect. *Herrerae* Knuth	3	15.33	1.154	0.075	16
sect. *Ionoxalis* (Small) Knuth	27	25	12.557	0.502	14
sect. *Lotoideae* Lourt.	9	26.44	18.049	0.682	16
sect. *Ortgieseae* Knuth	1	14	-	-	14
sect. *Oxalis*	3	28.33	6.506	0.229	22
sect. *Palmatifoliae* Reiche	2	28	0.000	0	28
sect. *Pseudobulbosae* Norl.	5	20.8	7.563	0.363	28
sect. *Rhombifoliae* (Knuth) Lourt.	1	80	-	-	80
sect. Ripariae Lourt.	2	10	0.000	0	10
sect. Roseae (Reiche) Knuth	2	13	1.414	0.108	14
Subg. Thamnoxys					
sect. Hedysaroideae DC.	1	18	-	-	18
sect. Polymorphae (Prog.) Lourt.	7	12.42	3.258	0.262	10
sect. Psoraleoideae Lourt.	3	12	0.000	0	12
sect. Robustae (Prog.) Lourt.	3	11.33	1.154	0.101	12
sect. Thamnoxys (Endl.) Progel	16	21	16.083	0.765	12

variations of the chromosomal number, with 2*n* = 12, 16, 24, 32, 44, 48.

Oxalis gigantea and *O. virgosa* are the two species of the sect. *Giganteae*, but only *O. gigantea* had its chromosomal number uncovered, with 2*n* = 18. Only *Giganteae* and *Ripareae* sections are represented by plants with more or less woody rigid stems with leaves and inflorescences in fascicles, but different chromosome numbers were observed in these sections, with *Ripareae* presenting 2*n* = 10. According to *Lourteig* (2000), in *Giganteae* the species have a stem with numerous short spur-like shoots and obcordate leaflets, whereas *Ripareae* includes species with stem entirely covered by leaves, with reduced internodes and suborbiculate leaflets.

In the sect. *Roseae*, composed by only one specie, *Oxalis rosea*, values *n* = 6, 7 and 2*n* = 14, 12 were found. This section is characterized by herbaceous habit with erect stem, fully adnate stipules and equal external and internal sepals. *Roseae* is better related to the sect. *Lotoideae*, cause both have species with herbaceous habit and flexible or creeping stem (Lourteig, 2000). However, only one *Lotoideae* group specie presented 2*n* = 14. These sections are differentiated by adnate stipules, leaflets with *calli* and rose or violet flowers present in the sect. *Roseae*.

The sect. *Ripariae*, according to Lourteig (2000) has nine species and only two were included in chromosome count studies, both with 2*n* = 10. *Oxalis hepatica* and *O. sarmentosa* have an herbaceous habit, with leaflets longer than 1 cm and many-flowered cymes. The sect. *Herrerae* is composed by four species, but only trhee were studied, *O. peduncularis* and *O. teneriensis*, both with 2*n* = 16 and *O. san-miguelli*, with 2*n* = 14. The main morphological difference between these sections is the stem, wich are succulent in *Herrerae* and more or less woody in *Ripariae* (Lourteig 2000).

In the sect. *Ionoxalis*, 14 species were investigated, revealing 2*n* = 12, 14, 20, 21, 28, 35, 36, 42, 54, 56. The value 2*n* = 14 was found in most species of this group, except *Oxalis bipartita*, 2*n* = 42, 54; *O. divergens* and *O. primavera*, both with 2*n* = 21; *O. eriolepis*, 2*n* = 12, 20 and *O. hispidula*, 2*n* = 35, 42. Within subg. *Oxalis,* the value 2*n* = 14 was also the most recorded in sect. *Articulatae*. These sections includes species with trifoliolate leaves; obcordate leaflets; pink, violet or white petals; sepals with *calli* and cylindrical capsules, being differentiated by the presence of bracteated bulb and stems that are reduced to a basal disc in sect. *Ionoxalis*, while in *Articulatae* it is common the presence of a vertically enlarged xylopodium and diminutive stems (Lourteig 2000).

In the sect. *Lotoideae*, composed by 33 species, only nine had their chromosomal numbers revealed, with 2n = 14, 16, 32, 48, 64. This section is characterized by the presence of succulent stem with evident internodes and oblong verrucous seeds (Lourteig 2000). The species *Oxalis andina*, *O. integra*, *O. medicaginea*, *O. mollissima* and *O. tabaconasensis* presented 2*n* = 16, and have in common filiform to linear bracts and bracteoles. The sect. *Rhombifoliae* has five species, but only *Oxalis rhombifoliae* was included in studies of chromosome counting, evidencing the value 2*n* = 80.

Oxalis niederleiniana and *O. triangularis* were the only species of the section *Pseudobulbosae* that had their chromosomal numbers studied, with 2*n* = 22 for *O. niederleiniana* and 2*n* = 12, 14, 28 for *O. triangularis*.

According to Lourteig (2000), this section is most related to the sect. *Oxalis*, cause their species possess succulent rhizome covered by spirally overlapping stipules and trifoliolate leaves. The sect. *Oxalis* includes seven species, but only *O. acetosella* and *O. griffithii* were studied, with $2n = 22$, 28 and $2n = 35$, respectively. The representatives of this section are distinguished by the presence of sepals and leaflets with *calli*, uniflora or umbelliform inflorescence and obcordate or subtriangular leaflets (Lourteig 2000).

The sect. *Palmatifoliae* includes 5 species, but only *Oxalis adenophylla* and *O. enneaphyla* were studied, with $2n = 28$. This value was also found in *Pseudobulbosae* and *Oxalis* sections which includes species with a more or less succulent rhizome covered by spirally overlapping stipules. *Palmatifoliae* stands out for the rhizome with petioles that remain at the apex of the stem, plurifoliolate leaves and oblong to linear leaflets (Lourteig 2000).

In *Oxalis* subg. *Thamnoxys* are found nine sections, which five were recorded in this article. The subg. *Thamnoxys* is characterized by the presence of 1-3 foliolate leaflets, with visible raquis; bilobed and capitated stigmas and transversely striated seeds. 23 species of the subg. *Thamnoxys* were analyzed and the chromosome numbers found was $2n = 10$, 12, 14, 16, 18, 19, 8, 36, 72 (Tab. 1). The sect. *Thamnoxys* presented the largest number of species sampled within this subgenus, with $2n = 12$ found in eight of the eleven species analyzed. This section is composed by herbs or sub-shrubs with leaves equally distributed along the stem and generally yellow decumbent flowers (Lourteig 1994, Abreu 2012).

The sect. *Robustae* comprises nine species and only three had their chromosomal numbers verified, *Oxalis grisea* and *O. juruensis* with $2n = 12$ and *O. praetexta* with $2n = 10$. It is characteristic of this section the presence of shrubs and sub-shrubs with trifoliolate leaves, ligulate stamens and transversely striated seeds with crevices (Lourteig 1994). The sect. *Psoraleoideae* includes five species that stand out by the shrub habit with pubescent indumentum; leaves distributed throughout the stem; stamens without a ligule or with a small ligula and verrucous seeds (Lourteig 1994). In this section, the species *Oxalis chartacea*, *O. erosa* and *O. psoraleoides* were analyzed, and the chromosomal pattern $2n = 12$ was observed.

Two other sections of the subg. *Thamnoxys* that had their chromosomal numbers investigated were *Polymorphae* and *Hedysaroideae*. In *Polymorphae* are found eight species of which five had their chromosomic numbers analyzed, with $2n = 10$, 12, 14, 19, not being perceived a pattern. This section is characterized by the presence of herbs or sub-shrubs with membranaceous leaves generally pooled at the apex or on pseudoverticils and transversely striated seeds with verrucous surface. The sect. *Hedysaroideae* is composed by six species, but only *Oxalis tessmannii* had the chromosomal number revealed, with $2n = 18$. This group differs morphologically from the sect. *Polymorphae* by the presence of leaves distributed throughout the stem, present in the sect. *Hedysaroideae*.

FINAL CONSIDERATIONS

We conclude that species belonging to the genus *Oxalis* do not present a pattern for their chromosome numbers when classified following the taxonomic framework proposed by Lourteig, and a same chromosome number could not be found for Lourteig's sections. Also, the n and $2n$ varied considerably, and many species presented polyploidy, differing from other representatives within the same subgenus.

REFERENCES

Abreu, M.C. 2007. Sistemática de *Oxalis* L.(Oxalidaceae R. Br.) no estado de Pernambuco, Brasil. Dissertação. 65f. Universidade Federal Rural de Pernambuco, Pernambuco.

Abreu, M.C. & Fiaschi, P. 2009. Oxalidaceae. Plantas da Floresta Atlântica. Available at: http://cncflora.jbrj.gov.br/ . Acessed on 22 January. 2013.

Abreu, M.C. & Fiaschi, P. Oxalidaceae. 2013. Jardim Botânico do Rio de Janeiro. Availableat http://floradobrasil.jbrj.gov.br/jabot/floradobrasil/FB12439>. Acessed on 17 September. 2014.

Abreu, M.C., Silva, M.J. & Sales, M.F. 2012. Análise cladística de *Oxalis* sec. *Thamnoxys* (Oxalidaceae) baseado em dados morfológicos. Rodriguésia 63:755-761.

Al-Bermani, A.K.K.A., Al-Shammary, K.I.A., Gornall, R.J. & Bailey, J.P. 1993. Contribution to a cytological catalogue of the British and Irish flora, 3. Watsonia 19:169–171.

Arohonka, T. 1982. Chromosome counts of vascular plants of the island Seili in Nauvo, southwestern Finland. Biologia Geographica 3:1–12.

Azkue, D. 2000. Chromosome diversity of South American *Oxalis* (Oxalidaceae). Botanical Journal of the Linnean Society 132:143–152.

Azkue, D. & Martínez, A. 1983. The chromosome complements of shrubby *Oxalis* species from South America. Plant Systematics and Evolution 141:187–197.

Azkue, D. & Martínez, A. 1984. Variacion del cariótipo, volumen nuclear y contenido de ADN en siete espécies de *Oxalis*. Darwiniana 25:267–277.

Azkue, D. & Martínez, A. 1988. DNA content and chromosome evolution in the shrubby *Oxalis*. Genome 30:52–57.

Azkue, D. & Martínez, A. 1990. Chromosome number of the *Oxalis tuberosa* alliance (Oxalidaceae). Plant Systematics and Evolution 169:25–-29.

Bedini, G., Garbari, F. & Peruzzi, L. 2012. Does chromosome number count? Mapping karyological knowledge on Italian flora in a phylogenetic framework. Plant Systematics and Evolution 298:39–750.

Denton, M.F. 1973. A monograph of *Oxalis*, section Ionoxalis (Oxalidaceae) in North America. Publications of the Museum Michigan State University 4:455–615.

Diers, L. 1961. Der Anteil an Polyploiden in den Vegetationsgürteln der Westkordillere Perus. Zeitschrift für Botanik 49:437–488.

Dmitrieva, S.A. 1986. Chromosome numbers in some species of vascular plants from Byelorussia. Botanicheskii Zhurnal 71:1145–1147.

Dobes, C., Hahn, B. & Morawetz, W. 1997. Chromosomenzahlen zur Gefässpflanzen-Flora Österreichs. Linzer Biologische Beiträge 29:5–43.

Dreyer, L.L. & Johnson, C. 2000. New chromosome number records of South African *Oxalis* species. South African Journal of Botany 66(2):130–132

Emshwiller, E. & Doyle, J.J. 2002. Origins of domestication and polyploidy in Oca (*Oxalis tuberosa*: Oxalidaceae). 2. chloroplast expressed glutamine synthetase data. American Journal of Botany 89:1042–1056.

Fiaschi, P. & Conceição, A.A. 2005. Oxalidaceae.: *In* Flora fanerogâmica do estado de São Paulo (Wanderley MGL, Shepherd GJ, Melhem TS, Giulietti AM eds). São Paulo: Fundação de Amparo à Pesquisa do Estado de São Paulo, Rima, p. 301–315.

Freeman, C.C. & Brooks, R.E. 1988. Documented plant chromosome numbers 1988: 1. Chromosome counts for North American plants - I. Sida 13:241–250.

Heitz, E. 1927. Ueber multiple und aberrante Chromosomenzahlen. Abhandlungen herausgegeben vom Naturwissenschaftlichen Verein zu Bremen 21: 47–57.

Judd, W.S., Campbell, C.S., Kellogg, E.A., Stevens, P.F. & Donoghue MJ. 2009. Plant systematics: a phylogenetic approach. Sinauer Associates, Sunderland. 464p.

Kapoor, B.M. & Ramcharitar S. 1982. IOPB chromosome number reports LXXVI. Taxon 31:596–597.

Knuth, R. 1930. Oxalidaceae. *In*. Das Pflanzenreich: regni vegetabilis conspectus. (Engler A, ed.) Leipzig :W. Engelmann, p. 1–481.

Laane, M.M. & Lie, T. 1985. Fremstillingav kromosom preparater med enkle metoder. Blyttia 43:7–15

Lourteig, A. 1983. Oxalidáceas. *In* Flora Ilustrada Catarinense. (Reitz R. ed.) Itajaí: Herbário Barbosa Rodrigues. parte I, 179 p.

Lourteig, A. 1994. *Oxalis* L. subgénero *Thamnoxys* (Endl.) Reiche emend. Lourt. Bradea 2(1):1– 199.

Lourteig, A. 2000. *Oxalis* L. subgéneros *Monoxalis* (Small) Lourt., *Oxalis* y *Trifidus* Lourt. Bradea 7:202–629.

Love, A. 1982. IOPB chromosome number reports LXXV. Taxon 31:344–360.

Marks, G.E. 1956. Chromosome numbers in the genus *Oxalis*. New Phytologist 55:120–129.

Mathew, P.M. 1958. Cytology of Oxalidaceae. Cytologia 23:200–210.

Mulligan, G.A. 1984. Chromosome numbers of some plants native and naturalized in Canada. Le Naturaliste Canadien 111:447–449.

Murray, B.G. & Lange, P.J.D. 1999. Contributions to a chromosome atlas of the New Zealand flora. Miscellaneous families. New Zealand Journal of Botany 37:511–521.

Nair, B.R. & Kuriachan, P. 2004. Cytogenetic evidence of the evolution of *Oxalis corniculata* var. *atropurpurea* Planch. Cytologia 69:149–153.

Nakajima, G. 1936. Chromosome numbers in some crops and wild angiosperms. The Japanese Journal of Genetics 12(4): 211–218.

Naranjo, C.A., Mola, L.M., Poggio, L. & Romero, M.M. 1982. Estúdios citotaxonomicos y evolutivos em especies herbaceas sudamericanas de *Oxalis* (Oxalidaceae). I. Boletin de la Sociedad Argentina de Botanica 20:183–200.

Nishikawa, T. 1982. Chromosome counts of flowering plants of Hokkaido. Report of the Taisetsuzan Institute of Science 17:9–16

Pashuk, K.T. 1987. Chromosome numbers in species of subalpine belt of Chernogora (Ukrainian Carpatians). Botanicheskii Zhurnal 72:1069–1074.

Plante, S. 1995. IOPB chromosome data 10. Int. Organ. Pl. Biosyst. Newslett 25:9–10.

Probatova, N.S. & Sokolovskaya, A.P. 1988. Chromosome numbers in vascular plants from Primorye Territory, the Amur River basin, north Koryakia, Kamchatka and Sakhalin. Botanicheskii Zhurnal 73:290–293.

Roy, S.C., Ghosh. S. & Chatterjee, A. 1988. A cytological survey of eastern Himalayan plants. II. Cell Chromosome 11:93–97.

Rutland, J.P. 1941. The Merton Catalogue. New Phytologist 40:210.

Salter, T.M. 1944. The genus *Oxalis* in South Africa: a taxonomic revision. South African Journal of Botany 1:1–355.

Sarkar, A.K., Datta, N., Chatterjee, U. & Hazra, D. 1982. IOPB chromosome number reports LXXVI. Taxon 31:576–579.

Scvortzoff, M.V. 2012 Relações filogenéticas e evolução cromossômica em espécies do gênero *Oxalis* (Oxalidaceae). Tese. 150f. Universidade Federal do Pernambuco, Pernambuco.

Sidhu, M.& Bir, S.S. 1983. Karyological studies on weeds on cultivable lands in Punjab, India. Tropical Plant Science Research 1:1–13.

Souza, F.O. & Bianchini, R.S. 2000. Flora fanerogâmica da Reserva do Parque Estadual das Fontes do Ipiranga: Oxalidaceae. Hoehnea 27:117–120.

Stace, C.A. 1989. Plant Taxonomy and Biosystematics. Cambridge University Press, New York,

Stevens, P.F. 2001. Angyosperm phylogeny website. 2001. Disponível em: <http://www.mobot.org/MOBOT/research/APweb/>. Acesso em 22 jan. 2011.

Vaio, M., Gardner, A., Emshwiller, E. & Guerra, M. 2013. Molecular phylogeny and chromosome evolution among the creeping herbaceous Oxalis species of sections Corniculatae and Ripariae (Oxalidaceae). Molecular Phylogenetics and Evolution 68:199–211.

Vaio, M., Gardner, A., Speranza, P., Emshwiller, E. & Guerra, M. 2016. Phylogenetic and cytogenetic relationships among species of *Oxalis* section *Articulatae* (Oxalidaceae). Plant Systematics and Evolution 302:1253–1265.

Warburg, E.F. 1938. Taxonomy and relationships in the Geraniales in the light of their cytology, 2. New Phytologist 37:198–210.

Weller, S.G. & Denton, M.F. 1976. Cytogeographic evidence for the evolution of distyly from tristyly in the North American species of *Oxalis* section *Ionoxalis*. American Journal of Botany 63:120–125.

Wulff, H.D. 1937. Chromosomen studien an der schleswigholsteinischen Angiospermen - Flora I. Berichte der Deutschen Botanischen Gesellschaft 55:262–269.

Yamashita, K. 1935. Zytologische Studien an Oxalis I. The Japanese Journal of Genetics 11(1): 36.

Xu, B.S., Weng, R.F.& Zhang, M.Z. 1992. Chromosome numbers of Shanghai plants I. Investigatio et Studium Naturae 12:48–65.