



RESEARCH ARTICLE

Comparative morphology and phenetics of *Nymphoides* species in Kerala

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ARTICLE HISTORY

Received: 23 January 2020

Accepted: 31 March 2020

Published: 02 May 2020

KEYWORDS

Nymphoides
Menyanthaceae
phenetics
dendrogram

ABSTRACT

Aquatic plants play an important role in maintaining the ecosystem balance. *Nymphoides* Seguiet (Menyanthaceae) is an emergent, rhizomatous or stoloniferous genus, commonly known as “floating hearts”, identified by its rounded or cordate, floating leaves, petiole like branches and unique floral characters. The present study deals with the comparative morphology and the phenetics of *Nymphoides* spp. in Kerala. These species are classified into two groups with the help of the dendrogram, which showed 66% dissimilarities among the two groups. *N. parvifolia* and *N. balakrishnanii* are closely related species in one group and *N. krishnakesara* and *N. macrosperma* are closely related species in other group.

Introduction

Menyanthaceae Dumort. are the most diverse and widespread family of aquatic and wetland plants under the order Asterales. The family has five genera with 60–70 species distributed all over the world. The five genera are *Menyanthes* L., *Liparophyllum* Hook. f., *Nephrophyllidium* Gilg., *Villarsia* Vent. and *Nymphoides* Seguiet. Of these five genera, *Nymphoides* are cosmopolitan in distribution. *Menyanthes* and *Nephrophyllidium* are restricted to Northern Hemisphere, *Liparophyllum* and *Villarsia* are found in Southern Hemisphere (11). The genus *Nymphoides* can be identified by its rounded or cordate, floating leaves, petiole like branches and its floral characters. *Nymphoides* species are both dioecious and monoecious.

The genus *Nymphoides* has 40–50 species in world, which are found in tropical regions of Africa, Australia, the Americas, India, and southeastern Asia (1, 5–8, 11). Eight species are found in India, seven of which are growing in Kerala (8). Recently two new species and one variety are reported (2, 3). The present study deals with the comparative morphology and phenetics of seven *Nymphoides* species in Kerala.

Materials and Methods

Seven *Nymphoides* spp. were collected from different parts of Kerala and conserved in the aquatic plant conservatory (Aquagene) of the Malabar Botanical Garden and Institute for Plant Sciences. The morphological and phylogenetic characters of the specimens were compared on the basis of visible characters. The phylogeny of seven species of *Nymphoides* in Kerala was done (Fig. 1 & Fig. 2).

The data for the analysis were collected from fresh material collected from different localities and also from herbarium specimens deposited in the Central National Herbarium (CAL), Botanical Survey of India, Southern Regional Centre (MH), Calicut University Herbarium (CALI) and Malabar Botanical Garden Herbarium (MBGH). In the present study, twenty two multi-state qualitative morphological characters of the *Nymphoides* spp. were considered (Table 1) and gave code numbers to the seven species (Table 2). The characters (with abbreviated codes) used in the cluster analysis with their character states are given in Table 1. The characters with two states were coded as 1 and 2 and also given continuous numbers when the character states are more than two. The results of multiple

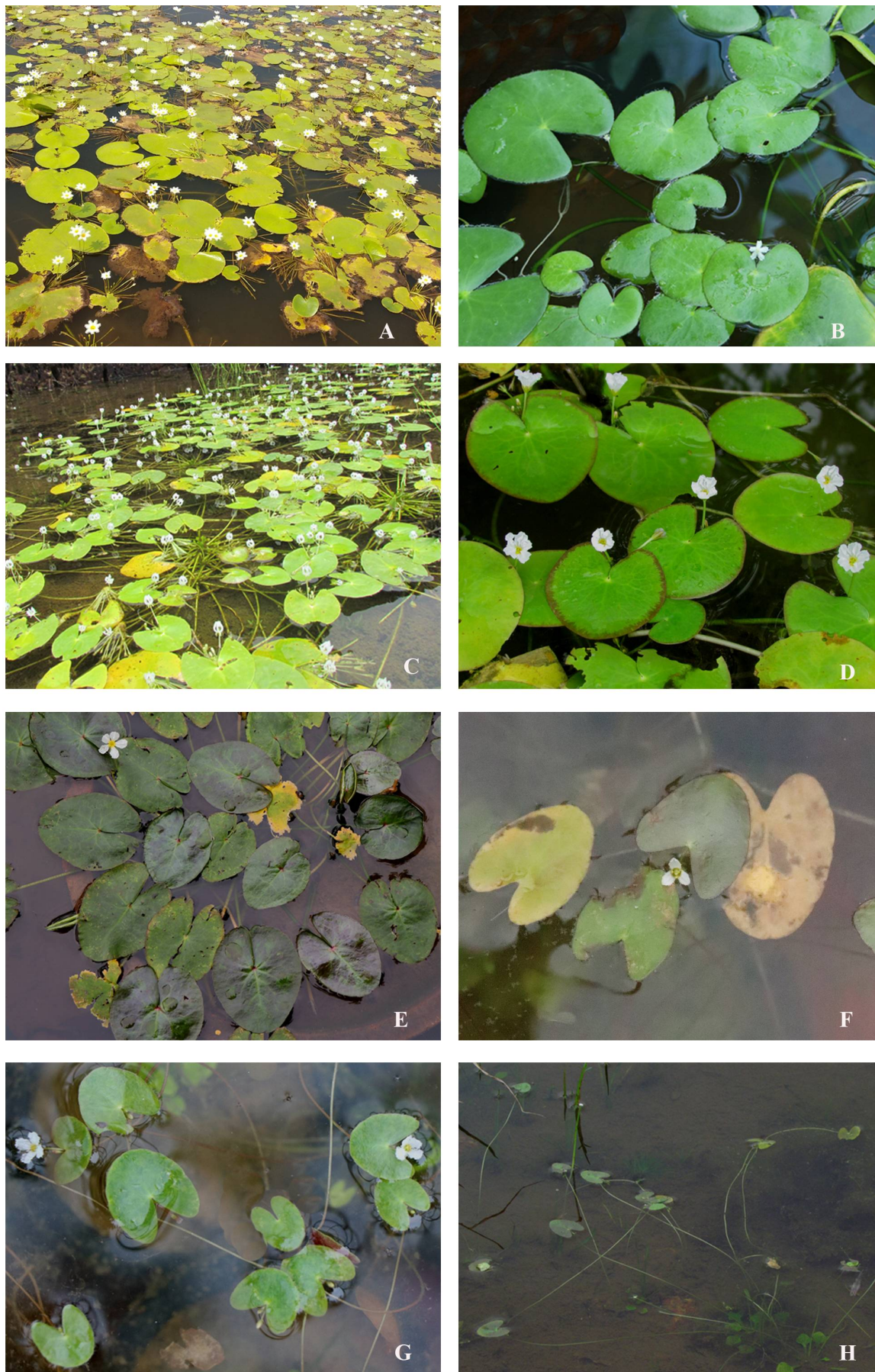


Fig.1. *Nymphoides* species in Kerala. **A.** *N. indica* (L) Kuntze, **B.** *N. macrospema* R.V.Nair, **C.** *N. krishnakesara* K.T. Joseph & Sivar., **D & E.** *N. hydrophylla* (Lour.) Kuntze, **F.** *N. parvifolia* Kuntze, **G.** *N. balakrishnanii* Biju, Josekutty, Haneef & Augustine., **H.** *N. palyii* Biju, Josekutty, Haneef & Augustine

range tests of characters of the OTUs are given in the Table 3. For cluster analysis, all the twenty two

characters were tabulated against the seven OTUs using the numerical codes given for character

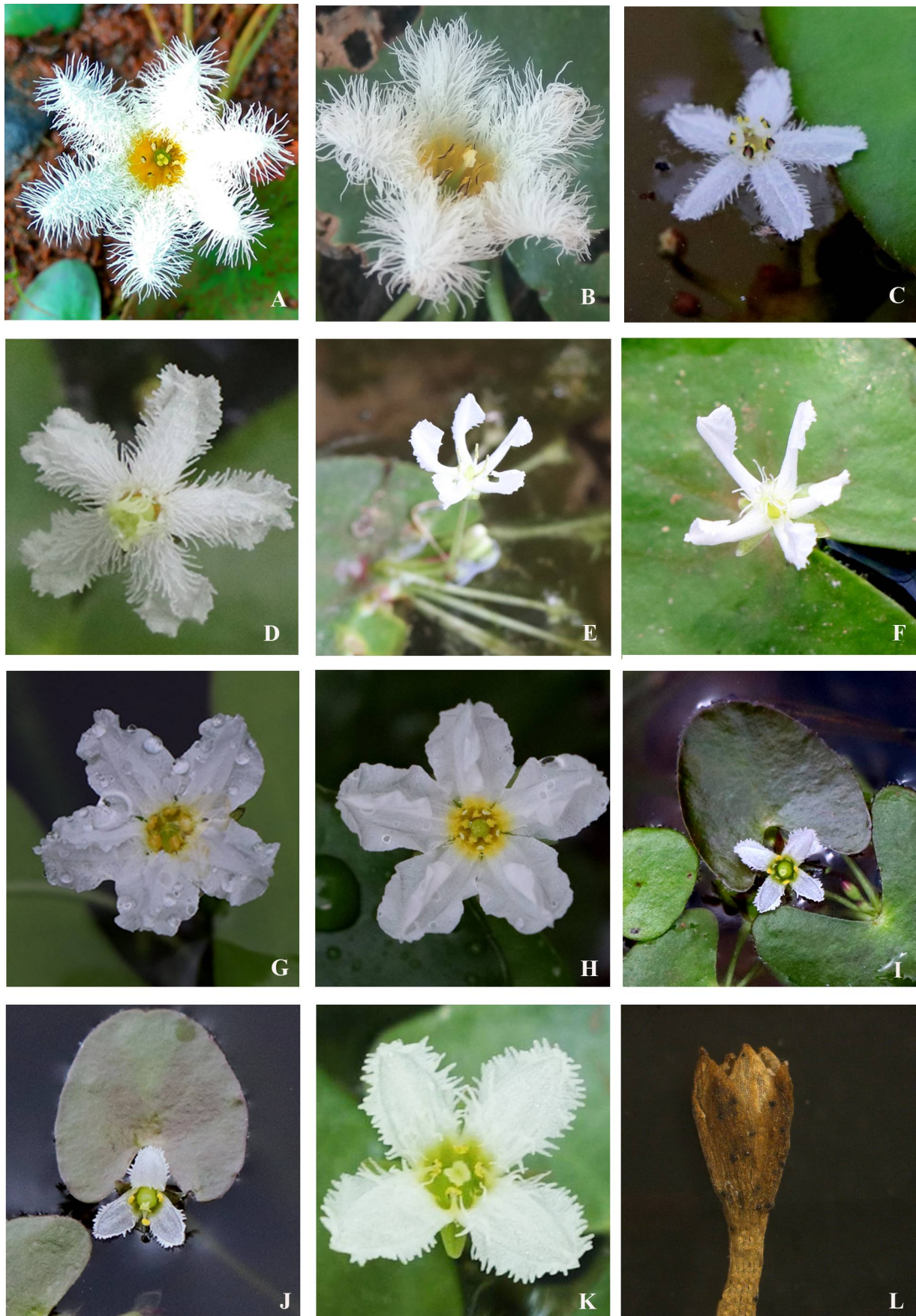


Fig. 2. Flowers of *Nymphoides* species in Kerala. **A & B.** Short styled and Long styled flowers of *N. indica*, **C & D.** Male and Female flowers of *N. macrosperma*, **E & F.** Male and Female flowers of *N. krishnakesara*, **G & H.** Bisexual & Female flowers of *N. hydrophylla*, **I & J.** Flowers of *N. parvifolia*, **K.** *N. balakrishnanii* flower, **L.** Flower of *N. palyii* (Herbarium)

states and abbreviated codes of characters (Table 4). These data were used to generate dendrogram using the statistical package STATISTICA version

7.0, adopting Unpaired Group Method with Arithmetic mean as algorithm (9) and percent disagreement (4) as the statistical test.

Table 1. Characters used in the cluster analysis

Sl. No.	Code	Characters	Characters states and their code numbers
1.	Hab	Habitat	Clay soil (1) or lateritic soil (2), clay soil and lateritic soil (3)
2.	Plt	Plant	Bisexual (1) or Unisexual (2), Bisexual and female (3)
3.	Rhi	Rhizome	Stoloniferous (1) or non stoloniferous (2)
4.	Sht	Shoot	Dimorphic (1) or monomorphic (2)
5.	Lvs	Leaves	Dimorphic (1) or Monomorphic (2)
6.	Flr	Flower	Bisexual (1), unisexual (2), bisexual or unisexual (3)
7.	ClxL	Calyx lobe	Oblong-acute (1), oblong-obtuse (2), linear-lanceolate (3), elliptic-lanceolate (4)
8.	Co	Corolla	White with yellow throat (1) or white (2)
9.	PetL	Petal lobe	Fimbriately toothed (1), shallowly fimbriate or undulate (2)
10.	PetLS	Shape of petal lobe	Obtuse or retuse (1), ovate to lanceolate (2), oblong-obtuse (3), oblong or elliptic (4)
11.	HrPL	Presence of hairs on petal lobe	Present (1) or absent (2)
12.	Stm	Stamen	Dimorphic (1) or monomorphic (2)
13.	ClrA	Colour of Anther	Yellow (1), pale purple (2), blue (3), black with yellow (4), Cream (5)
14.	NoSt	No. of stamens	Three or four (1), four (2), five (3), four to eight (4)
15.	ISG	Inter staminal gland	Present (1) or absent (2)
16.	ArC	Stigmatic hair	Present (1) or absent (2)
17.	Stl	Style	Heterostylous (1) or homostylous (2)
18.	HgG	Hypogynous gland	Hairy (1), hairless (2)
19.	Fr	Fruit	Ellipsoid (1), sub globose (2), obovoid (3), oblong (4), or oblong to obovoid (5)
20.	Se	Seed	Tuberculate (1) or smooth (2)
21.	SeS	Shape of seed	Discoid (1), obovate or elliptical (2), Obovoid (3)
22.	PoS	Pollen shape	Prolate-spheroidal (1), prolate-spheroidal to subprolate (2) or oblate-spheroidal (3)

Phenetics

Phenetics (also known as taxometrics) is a method to classify organisms based on the overall morphological similarity notwithstanding the evolutionary relationships/ characters. In the present study the results of multiple range tests of characters of the OTUs are given in the Supplementary Table 1. For cluster analysis, all the twenty two characters were tabulated against the seven OTUs using the numerical codes given for character states and abbreviated codes of twenty two characters.

Table 2. *Nymphoides* spp. (OTUs) selected for the study

Code No.	Name of the species (OTUs)
1.	<i>Nymphoides indica</i> (L.) Kuntze
2.	<i>Nymphoides macrosperma</i> R.V.Nair
3.	<i>Nymphoides krishnakesara</i> K.T. Joseph & Sivar.
4.	<i>Nymphoides hydrophylla</i> (Lour.) Kuntze
5.	<i>Nymphoides parvifolia</i> Kuntze
6.	<i>Nymphoides balakrishnanii</i> Biju, Josekutty, Haneef & Augustine
7.	<i>Nymphoides palyii</i> Biju, Josekutty, Haneef & Augustine

Results and Discussion

The genus *Nymphoides* in Kerala state is represented by nine species and one variety, namely, *Nymphoides aurantiacum*, *N. balakrishnanii*, *N. hydrophylla*, *N. indica*, *N. krishnakesara*, *N. krishnakesara* var. *bispinosa*, *N. macrosperma*, *N. parvifolia*, *N. palyii* and *N. sivarajanii*. Eventhough after extensive explorations in the previous known localities, we could not relocate *N. aurantiacum*, *N. krishnakesara* var. *bispinosa* and *N. sivarajanii* and hence, they were not included in the present study. The worst flood occurred in Kerala state in 2018 may also adversely affected the fragmented population of these highly vulnerable species.

Key to the species of *Nymphoides* in Kerala

- 1a. Flowers corolla upto 40 mm in diam., distylous; corolla upper side totally covered with dense hairs. *N. indica*
- 1b. Flowers corolla upto 22 mm in diam., small, homostylous; corolla partially or not covered with hairs (2)
- 2a. Plants dioecious; stigma bilobed with a whorl of radiating glandular hairs (3)
- 2b. Plants monoecious or gynodioecious; stigma bilobed without a whorl of radiating glandular hairs (4)
- 3a. Shoot dimorphic, many jointed each joint bearing single leaf; leaves monomorphic; corolla lobes without median wings; hypogynous glands hairy *N. macrosperma*
- 3b. Shoot monomorphic, single leaf arising from the axils of rhizome; leaves dimorphic; corolla lobes with median wings; hypogynous glands not hair *N. krishnakesara*
- 4a. Flowers unisexual (female) or bisexual; corolla lobes not fimbriate, undulate margine with upper median wing; seeds 2 mm across. *N. hydrophylla*
- 4b. Flowers bisexual; corolla lobes fimbriate without median wing; Seeds small, less than 2 mm across (5)
- 5a. Petals 4 in number; floating leaves obovate – orbicular; calyx exceeds the fruit *N. balakrishnanii*
- 5b. Petals 3 or 4 in number; floating leaves ovate – orbicular; calyx not exceeds the fruit (6)
- 6a. Floating leaves pale green – brownish green with pinkish tinge; hypogynous gland present; seed surface tuberculated *N. parvifolia*
- 6b. Floating leaves dark green; hypogynous gland not distinct; seed surface smooth *N. palyii*

The result of comparative morphology of the seven *Nymphoides* spp. is given in Supplementary Table 1. The dendrogram of seven *Nymphoides* spp. in Kerala was obtained through the cluster analysis, using character states of the OTUs and resulted the percent disagreement between OTUs (Table 5 & Fig. 3). The results of dendrogram clearly revealed that the seven species come into two distinct groups Group I and Group II.

Group 1: 1, 5, 6 & 7

Group II: 2, 3 & 4

Group I and Group II were clustered together and show 66% dissimilarities. Group I is classified into Group IA and Group IB. In Group I *Nymphoides indica* is clustered distantly from other species and shows 55% dissimilarities from other species viz.,

Nymphoides parvifolia, *N. balakrishnanii* and *N. palyii*. Group IB is again classified into Group IB₁ and Group IB₂. *N. palyii* is come under Group IB₂ and are separated from *N. balakrishnanii* and *N. parvifolia* (Group IB₁). *N. palyii* shows 34% dissimilarities with other two species. These two species come in Goup IB₁ are closely related, which shows highest affinities (68% similarities).

Group II consists of two clusters Group IIA and Group IIB and represents three taxa viz., *N. hydrophylla*, *N. krishnakesara*, *N. macrosperma*. Group IIB is separated from Group IIA which consists of two taxa viz., *N. krishnakesara* and *N. macrosperma*. Group IIB is 60% dissimilar with Group IIA. In this study *N. krishnakesara* is clustered together with *N. macrosperma* instead of *N. hydrophylla*. *N. krishnakesara* shows more similarity (50%) with *N. macrosperma* than *N. hydrophylla*. On

Table 3. Results of multiple range test of characters

Code for Characters	Characters	Grouping of Taxa (represented by code numbers) according to their character states				
		1	2	3	4	5
Hab	Habitat	Clay soil 2, 4	Laterite soil 3, 5, 6, 7	Caly soil and laterite soil 1		
Plt	Plant	Bisexual 1, 5, 6, 7	Unisexual 2, 3	Bisexual and female 4		
Rhi	Rhizome	Stoloniferous 1,2,4	Nonstoloniferous 3, 5,6, 7			
Sht	Shoot	Dimorphic 1, 2, 4	Monomorphic 3, 5, 6, 7			
Lvs	Leaves	Dimorphic 3, 5, 6, 7	Monomorphic 1, 2, 4			
Flr	Flower	Bisexual 1, 5, 6, 7	Unisexual 2, 3	Bisexual and unisexual 4		
ClxL	Calyx lobe	oblong-acute 1, 5	Oblong-obtuse 2, 3	Linear- lanceolate 4, 6	Elliptic- lanceolate 7	
Co	Corolla	White with yellow throat 1, 4, 5, 6, 7	white 2, 3			
PetL	Petal lobe	Fimbriately toothed 1, 2, 3, 5, 6, 7	Undulate 4			
PetLS	Shape of petal lobe	Obtuse or retuse 4	ovate to lanceolate 1, 6, 7	Oblong or obtuse 3	oblong or elliptic 2, 5	
HrPL	Presence of hairs on petal lobe	Present 1, 2, 5, 6, 7	Absent 3, 4			
Stm	Stamen	Dimorphic 1	Monomorphic 2, 3, 4, 5, 6, 7			
ClrA	Colour of Anther	Yellow 4, 5	Pale purple 1, 2	Blue 3	Black with yellow 6	Cream 7
NoSt	No. of stamens	Three or four 5, 7	Four 6	Five 2, 3, 4	Four to eight 1	
ISG	Inter staminal gland	Present 1, 2, 3, 4, 5, 6	Absent 7			
ArC	Stigmatic hair	Prsent 2, 3	Absent 1, 4, 5, 6, 7			
Stl	Style	Heterostylous 1	Homostylous 2, 3, 4, 5, 6, 7			
HgG	Hypogynous gland	Hairy 1, 2, 4, 6	Hairless 3, 5	Absent 7		
Fr	Fruit	Ellipsoid 1, 5	Sub globose 2	Obovoid 3	Oblong 4, 7	Oblong to obovoid 6
SeO	Seed ornamentation	Tuberculate 2, 3, 4, 5, 6	Smooth 1, 7			
SeS	Seed shape	Discoid 1, 4, 5, 6, 7	Obovate or ellipsoid 2	Obovoid 3		
PoS	Pollen shape	Prolate-spheroidal 1, 3, 4, 6	Prolate-spheroidal to subprolate 2	Oblate-spheroidal 5, 7		

Table 4. Character states of the OTUs

Character codes	Codes for OTUs						
	1	2	3	4	5	6	7
Hab	3	1	2	1	2	2	2
Plt	1	2	2	3	1	1	1
Rhi	1	1	2	1	2	2	2
Sht	1	1	2	1	2	2	2
Lvs	2	2	1	2	1	1	1
Flr	1	2	2	4	1	1	1
ClxL	1	2	2	3	1	3	4
Co	1	2	2	1	1	1	1
PetL	1	1	1	2	1	1	1
PetLS	2	4	3	1	4	2	2
HrPL	1	1	2	2	1	1	1
Stm	1	2	2	2	2	2	2
ClrA	2	2	3	1	1	4	5
NoSt	4	3	3	3	1	2	1
ISG	1	1	1	1	1	1	2
ArC	2	1	1	2	2	2	2
Stl	1	2	2	2	2	2	2
HgG	1	1	2	1	2	1	3
Fr	1	2	3	4	1	5	4
Se	2	1	1	1	1	1	2
SeS	1	2	3	1	1	1	1
PoS	1	2	1	1	3	1	3

the basis of morphological data (including pollen, seed and flavonoid data) and molecular data (10) the floating-leaved genus *Nymphoides* was reported as monophyletic, except for *N. exigua*. Based on the morphological and molecular study the Indian species of *Nymphoides* viz. *N. hydrophylla*, *N. parvifolia* and *N. sivarajanii* were closely related to *N. krishnakesara* and *N. macrosperma* (12). The phenetic analysis of seven species of *Nymphoides* spp. gives a picture on the affinities of *Nymphoides* spp. in Kerala. The results shows that *N. parvifolia* and *N.*

Table 5. Percent disagreement between OTU's under study

OTU	OTU's arranged as per their numerical codes						
	1	2	3	4	5	6	7
1	0.00	0.64	0.86	0.59	0.55	0.50	0.59
2	0.64	0.00	0.50	0.55	0.68	0.68	0.82
3	0.86	0.50	0.00	0.68	0.55	0.55	0.68
4	0.59	0.55	0.68	0.00	0.64	0.55	0.73
5	0.55	0.68	0.55	0.64	0.00	0.32	0.32
6	0.50	0.68	0.55	0.55	0.32	0.00	0.36
7	0.59	0.82	0.68	0.73	0.32	0.36	0.00

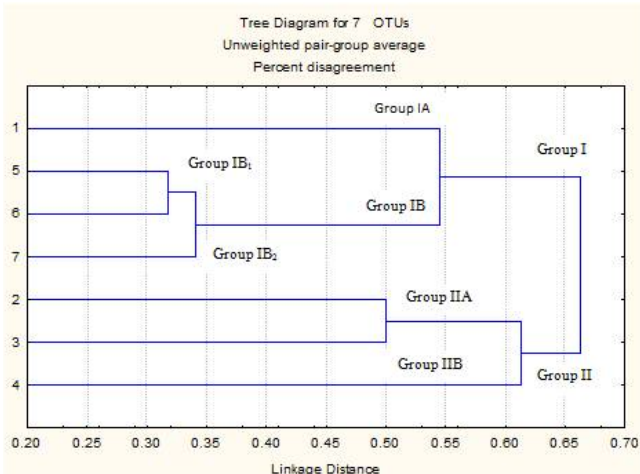


Fig 3. Dendrogram of seven species of *Nymphoides* in Kerala. 1. *N. indica*, 2. *N. macrosperma*, 3. *N. krishnakesara*, 4. *N. hydrophylla*, 5. *N. parvifolia*, 6. *N. balakrishnanii*, 7. *N. palyii*.

balakrishnanii are closely related species and shows highest affinities. *N. krishnakesara* and *N. macrosperma* in Group II also shows high affinity. *Nymphoides* spp. of Kerala shows two groups showing 66% dissimilarities.

Specimens examined

a. *Nymphoides indica*: INDIA. Kerala: Kottayam District, Vaikom, 21 April 1988, Swaminathan M. S. 88274 (CAL!). Trichur District, Paliappara, Chalakkudy, 22 Septmeber 1982, Ramamurthy 74703; *ibid.*, Ramamurthy 74863 (CAL!). Alappuzha District, Kanichukulangara junction, *s.die*, Sunil C. N. 2210 (CALI!); *ibid.*, Angadikal, *s.die*, Sunil C. N. 2624 (CALI!); Kasaragod District, Peelikode, 16 February 2007, Suresh K. K. 03152 (MBGH!). Kozhikode District, Olavanna, 25 September 1999, Krishnan P. N. 825 (MBGH!); *ibid.*, 27 November 2015, Pavisha P. 12370 (MBGH!); Oorkadavu, 27 June 2008, Suresh K. K. 03994 (MBGH!); Pantheerankavu, 21 December 2016, Pavisha P. 12375 (MBGH!). Kasaragod District, Peelikode, 16 February 2007, Suresh K. K. 03317 (MBGH!); Kayyur, 05 February 2007, Suresh K. K. & Jaris P. K. 04405 (MBGH!); *ibid.*, *s. die*, Suresh K. K. & Jaris P. K. 03181 (MBGH!).

b. *Nymphoides macrosperma*: INDIA. Kerala: Kozhikode District, Olavanna, 14 July 2006, Krishnan P. N. 2064 (MBGH!); Pantheerankavu, 22 February 2016, Pavisha P. 12372 (MBGH!).

c. *Nymphoides krishnakesara*: INDIA. Kerala: Kannur District, Madaippara, 25 October 1988, Joseph K. T. 43001 (MH!); *ibid.*, 20 September 2005, Krishnan P. N. & Ansari R. 2563 (MBGH!); *ibid.*, 04 September 2008, Suresh K. K. 4004 (MBGH!); *ibid.*, 12 December 2016, Pavisha P. Rajilesh V. K. & Ajesh P. P. 12373 (MBGH!); Payyannur, 29 July 2009, Suresh K. K. 4964 (MBGH!); *ibid.*, 07 October 2008, Suresh K. K. 4288 (MBGH!); *ibid.*, 04 September 2008, Suresh K. K. & Jaris P. K. 3317 (MBGH!); Korom, 15 January 2019, Pavisha P, Jaseela V. T & Sinisha P. 17748 (MBGH!).

d. *Nymphoides hydrophylla*: British Burma, 04 January 1971, *S Kurz*. 2264 (CAL – Holotype!). INDIA. Kerala: Palakkad District, Elavanchery, 02 November 1976, Vajravelu M. S. 48836 (CAL!). Kannur District, Ezhuvamalai, 17 December 1979, Ramachandran 65266 (CAL!); *ibid.*, 20 July 1981, Ansari R. 70966 (CAL!). Thrissur District, Chalakudi, 15 September 1976, Ramamurthy 48535 (CAL!). Thiruvananthapuram District, Pulimath, 02 December 1977, Mohanan 52675 (CAL!). Kasaragod District, Peelikode, 06 February 2007, Suresh K. K. & Jaris P. K. 03162 (MBGH!); Kayyur, 06 February 2007, Suresh K. K. & Jaris P. K. 03188 (MBGH!). Kollam District, 16 February 2007, Suresh K. K. 03229 (MBGH!). Idukki District, Moolamattam, 17 December 2008, Suresh K. K. 04436 (MBGH!). Malappuram District, Koottumoochi, 18 November 2011, Anoop K. P. & Hareesh K. T. 6537 (MBGH!); Kozhikode District, Palazhi, 22 February 2016, Pavisha P. 12371 (MBGH!).

e. *Nymphoides parvifolia*: INDIA. Kerala: Kasaragod, Beemanadi, 27 September 1982, Ansari R. 74328 (CAL!); *ibid.*, 18 December 2008, Suresh K. K. 4954 (MBGH!); Kayyur, 07 December 2018, Pavisha P, Hridhya P & Ajesh P. P. 15813 (MBGH!).

f. *Nymphoides balakrishnanii*: INDIA. Kerala: Kasaragod, Koovappara, 24 January 2019, *Pavisha P.* 17747 (MBGH!).

g. *Nymphoides palyii*: INDIA. Kerala: Kasaragod, Perla, 19 September 2016, *Anoop K. P. & Rajilesh V. K.* 14595 (MBGH!); *ibid.*, 07 December 2018, *Pavisha P., Hridhya P. & Ajesh P. P.* 15831 (MBGH!).

Authors' contributions

PP carried out the field studies, identified the specimens and prepared the manuscript. MPV and PNS confirmed the species identity and helped in the manuscript preparation. All authors read and approved the final manuscript.

Acknowledgements

The authors are thankful to the Kerala State Council for Science Technology & Environment (KSCSTE) for financial support. The authors are thankful to the Director, KSCSTE Malabar Botanical Garden & Institute for Plant Science for providing the facilities. We also acknowledge the support and help provided by Dr. Mohanan K. V., Professor of Genetics, Calicut University in the preparation of the Dendrogram.

Competing Interest

The authors declare that they have no competing interests.

Supplementary file

[Supplementary Table 1](#)

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