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RESEARCH ARTICLE

Growth and flowering dynamics of lotus (*Nelumbo nucifera*) genotypes: Exploring their potential for floriculture and aquatic gardening

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Abstract

This study investigated the growth characteristics and flowering patterns of various *Nelumbo nucifera* (lotus) genotypes to identify optimal selections for aquatic garden applications. Thirty genotypes of *Nelumbo nucifera* (Asian lotus) were evaluated under standardized conditions. Parameters measured included rate of rhizome formation, leaf production, time to first flowering, flower quantity and bloom duration. Significant differences were observed among genotypes in growth habit, flowering time and environmental adaptability. The genotypes Nn-6, Nn-16 and Nn-2 recorded early flower emergence, while Nn-2, Nn-16 and Nn-30 recorded a higher number of flowers per plant. Based on superior performance across multiple assessment criteria, particularly in terms of faster establishment, plant height, flower type and size, the genotypes were classified as small, medium and large types. Performance was notably affected by factors such as water depth, temperature and nutrient availability. These findings provide evidence-based recommendations for selecting lotus genotypes best suitable for specific aquatic gardens and conditions, while highlighting the potential of lesser-known cultivars in aquatic landscaping.

Keywords: aquatic gardening; container gardening; heat tolerance; *Nelumbo nucifera*; urban landscaping

Introduction

Nelumbo nucifera is a popular aquatic plant belonging to the family Nelumbonaceae with a chromosome number (2n = 16). Its roots remain 15-40 cm below the water surface in the muddy substrate of water bodies like lakes, ponds and rivers. Lotus is propagated by seeds and rhizomes. For commercial cultivation, rhizomes are preferred. The plants grow by expanding its creeping runners that grow in anaerobic sediments beneath the mud. *Lotus (Nelumbo spp.)* has long been valued for its cultural significance, versatility and aesthetic appeal in aquatic gardens worldwide. The genus consists of two species: *Nelumbo nucifera* Gaertn. (Asian or sacred lotus) and *Nelumbo lutea* Willd. (American lotus), Both produce spectacular flowers and distinctive foliage that transform water features into focal points of visual interest. (*N. nucifera* is the national flower of both India and Vietnam. The Asian lotus is revered as the Sacred Lotus due to its religious importance in Hinduism and Buddhism.

Lotus is also recognised for its multiple uses beyond ornamental value. Its seeds, rhizomes and leaves have long been used in traditional medicine, cuisine and religious ceremonies (1). Lotus contains bioactive compounds such as flavonoids (e.g. quercetin, kaempferol), alkaloids (e.g. nuciferine, liensinine) and polyphenols (e.g. catechin, gallic acid), which contribute to its antioxidant, anti-inflammatory and antimicrobial properties (2). These attributes have spurred increased interest in its cultivation not only as an ornamental plant but also as a functional and medicinal crop.

Despite the increasing popularity of aquatic gardening and multifunctional use of lotus, research on the comparative performance of different lotus genotypes remains limited. The cultivation of lotus presents unique challenges compared to terrestrial ornamentals, requiring specialized knowledge of factors such as water depth requirements, dormancy patterns and rhizome management (3). While traditional cultivars have been familiar in horticulture, many newer or lesser-known genotypes with superior garden performance remain understudied (4, 5). Furthermore, climate adaptability and flower longevity are more important traits in the selection of lotus cultivars for landscapes and aquatic gardens (6). With rapid urbanization and growing interest in designing aquatic gardens, the demand for low-maintenance, more aesthetically pleasing aquatic ornamentals like lotus has surged in recent years (7). This research aims to address this knowledge gap by systematically evaluating key growth and flowering characteristics of diverse lotus genotypes, evaluating growth and flowering parameters of lotus genotypes and identifying superior performers for different garden applications.

By generating empirical data on comparative performance, this study provides valuable information for horticulturists, landscapists, nursery professionals and home gardeners seeking to maximize the ornamental and functional potential of lotus in aquatic gardens.

Materials and Methods

Thirty lotus genotypes with three replications of each were selected for evaluation (Table 1). Selection criteria included genotypes with a wide range of colours, variation in growth habit, flower characteristics and putative adaptability to the growing season. Genotypes sourced from different regions were authenticated using standard morphological descriptors for *Nelumbo nucifera* as outlined in the "Descriptors for Lotus (*Nelumbo nucifera* Gaertn.)," ICAR-National Bureau of Plant Genetic Resources (ICAR-NBPGR), New Delhi (2015), ensuring correct identification before planting. Dormant rhizomes of uniform size (150 ± 20 g) were obtained from established collections from various lotus cultivation sources such as aquatic gardens, nurseries and conservatories in India (Table 1) in January 2023.

The experiment was conducted in the TNAU Botanical Garden, Coimbatore, Tamil Nadu, India (11°02' N Latitude, 76°57' E Longitude at an altitude of 426.76 m above MSL) during the 2024 growing season (Feb-Sep). The experimental design consisted of a Completely Randomized Design (CRD) with three replications. Each experimental unit consisted of a 50 L plastic container (16 inch bottom diameter, 18 inch top diameter and 14 inch height). Media filled with 20 cm of loam soil (pH 6.8) amended with 4 % composted manure by volume as a substrate, followed by 15 cm of water above the soil surface.

To simulate real garden conditions, containers were placed outdoors with full sun exposure (minimum 8 hours of direct sunlight daily). Water was refilled as needed to maintain the required depth and algae were manually removed weekly to prevent competition. Occasional water overflow was used as a method to reduce algal growth and maintain water clarity. Water temperature was monitored continuously using digital data loggers. During the experimental period, water temperature ranged from 18 °C to 32 °C, with a mean of 24 °C., Air temperature ranged from 20 °C to 36 °C, with a mean of 28 °C Relative Humidity ranged from 58.6 % to 78.6 % with a mean of 68.6 %. Water depth was maintained at 15 ± 3 cm throughout the growing season. A slow-release aquatic fertilizer (19:19:19 NPK) was incorporated into the substrate at planting at a rate of 5 g per container. Supplemental fertilization (10 g DAP fertilizer) was applied at 30-day intervals beginning when the first floating leaves appeared.

Data collection and analysis

Growth parameters were monitored throughout the growing season. Data collected included:

Table 1. Accession details and place of collection

S. No	Acc.No	Genotypes name	Sources
1	Nn-01	Pink cloud	Tamil Nadu
2	Nn-02	Affection 16	Tamil Nadu
3	Nn-03	Saim Ruby	Tamil Nadu
4	Nn-04	Green Apple	Kerala
5	Nn-05	Red Eden	West Bengal
6	Nn-06	Amiry Camelia	Pondicherry
7	Nn-07	Rani Red	Kerala
8	Nn-08	Aishwariya	Odisha
9	Nn-09	Akila	Pondicherry
10	Nn-10	Namo	Karnataka
11	Nn-11	Bucha	Karnataka
12	Nn-12	Super Pink	Kerala
13	Nn-13	Amiry Peony	Pondicherry
14	Nn-14	Crystal Pink	Kerala
15	Nn-15	Red Sanghai	Kerala
16	Nn-16	Yellow Port Pink	Tamil Nadu
17	Nn-17	White peony	Andhra
18	Nn-18	Red peony	Andhra
19	Nn-19	Juliet	Kerala
20	Nn-20	Kaveri	Tamil Nadu
21	Nn-21	White Swan	Tamil Nadu
22	Nn-22	Thousand petals	Tamil Nadu
23	Nn-23	Thamo	Tamil Nadu
24	Nn-24	Lakshmi	Tamil Nadu
25	Nn-25	Miracle	Tamil Nadu
26	Nn-26	Yellow Peony	Pondicherry
27	Nn-27	White Puff	Pondicherry
28	Nn-28	Octopus	Kerala
29	Nn-29	Wadsana	Kerala
30	Nn-30	Liang -li	Kerala

Establishment rate

Days from planting to the emergence of the first floating leaf

Vegetative growth

Number of leaves counted at weekly intervals

Rhizome development

Fresh weight of rhizomes measured at the end of the growing season

Flowering performance

Days to first flower, total number of flowers per plant and bloom duration

Environmental adaptability

Observable stress symptoms under fluctuating temperature conditions, such as reduction in leaf size, new leaf formation and bud abortion.

Statistical analysis was performed using R software (version 2025). Analysis of variance (ANOVA) was conducted to determine significant differences among treatments. Tukey's honest significant difference (HSD) test was employed for mean separation at the 5 % significance level.

Results

The results of this study provide valuable insights into the comparative performance of diverse *Nelumbo nucifera* genotypes under standardized growing conditions. Significant differences ($p < 0.05$) were observed among genotypes in establishment rate and vegetative growth (Table 2-3). Genotypes Nn-6, Nn-12 and Nn -20 demonstrated the fastest establishment, producing their first floating leaves within 10-11 days after planting, while Nn-13 and

Nn-30 required around 15 days. The genotype Nn-30 recorded earlier production of aerial leaf (15.24 ± 4.20), followed by Nn-6 (20.45 ± 0.70) and Nn-2 (20.66 ± 1.04). The genotypes Nn-22, Nn-25 and Nn-23 have taken a higher number of days, such as (31.33 ± 0.64), (30.00 ± 1.40) and (29.66 ± 0.55) respectively (Table 3). The genotype Nn-30 had produced the highest number of leaves (44.57 ± 1.44), followed by Nn-16 (40.65 ± 0.05) and Nn-11(40.56 ± 2.11). The cultivars Nn-1 and Nn-7 produced fewer but more compact standing leaves (30.11 ± 0.26 and 34.16 ± 0.68 respectively), with less difference. Leaf production patterns showed two distinct growth strategies among the genotypes. Most *N. nucifera* cultivars exhibited steady leaf production throughout the growing season, followed by reduced production in the late season.

Flowering performance

Flowering performance showed the greatest variation among the evaluated parameters (Table 4 and Fig. 1). Genotypes were classified into early flowering (≤ 40 days), medium flowering (41-55 days) and late flowering (> 55 days) categories, based on the number of days from planting to first flower opening. The earliest flowering was observed in Nn-6, which produced its first flowers at (30.76 ± 0.78) days after planting. Nn-16 and Nn-2 also demonstrated relatively early flowering (37.76 ± 0.53) and (38.46 ± 0.16) days. In contrast, Nn-22 and Nn-11 required significantly longer periods 79.45 ± 4.10 and 74.43 ± 3.69 days to initiate flowering. Nn-2 produced the highest number of flowers per plant (20.66 ± 0.60), followed by Nn-6 (16.00 ± 0.22) and Nn-30 (15.98 ± 2.61).

The double-flowered genotypes Nn-22, Nn-11 and Nn-29 produced fewer flowers (4.23 ± 0.21), (4.33 ± 0.14) and (5.33 ± 0.13) but more elaborate flowers that persisted longer field. Nn-22 recorded a maximum field life of (5.98 ± 0.08) days.

Rhizome development

Cultivation in plastic containers can shorten the cropping period, as plants often transition to the reproductive phase earlier than those grown in natural water bodies. This accelerated phenological development is advantageous for rhizome formation, as it allows timely initiation and maturation within a controlled environment. Furthermore, container-based culture facilitates easier determination and harvesting of rhizomes at the optimal stage compared to large water bodies, where retrieval is more labour-intensive and timing is less precise. End-of-season rhizome development varied significantly among genotypes (Table 4). By the end of the growing season, Nn-30 produced the highest number of rhizomes (8.00 ± 0.16), representing a 627 % increase from the initial planting stock. Nn-2 and Nn-16 also demonstrated vigorous rhizome development (7.00 ± 0.07 and 7.00 ± 0.01 numbers, respectively). Small cultivars showed a comparatively greater number of rhizomes. This characteristic makes these cultivars particularly suitable for container gardens where space restriction is desirable. Rhizome shape also differed noticeably among genotypes. Rhizomes of small cultivars were shorter and slender, whereas large cultivars had longer internodes and a thicker girth. Nn-30, Nn-2, Nn-16 and Nn-26 developed more compact, densely branched, smaller-sized rhizomes, while Nn-24, Nn-18, Nn-23 and Nn-24 produced rhizomes with more internodal length and more girth with fewer branches.

Table 2. Days taken for emergence of coin leaf (CL), Floating leaf (FL) and Aerial leaf (AL)

Acc. No	CL	FL	AL
Nn-1	4.66 ± 0.23	11.33 ± 0.34	22.00 ± 0.17
Nn-2	4.33 ± 0.01	11.33 ± 0.19	20.66 ± 1.04
Nn-3	5.66 ± 0.17	12.00 ± 0.23	23.66 ± 1.12
Nn-4	5.33 ± 0.20	11.00 ± 0.38	28.33 ± 1.12
Nn-5	5.66 ± 0.18	11.33 ± 0.42	21.33 ± 0.31
Nn-6	4.66 ± 0.19	10.33 ± 0.09	20.45 ± 0.70
Nn-7	4.69 ± 0.12	12.33 ± 0.63	24.69 ± 0.70
Nn-8	4.33 ± 0.11	13.33 ± 0.41	24.33 ± 0.40
Nn-9	5.33 ± 0.00	12.00 ± 0.15	29.00 ± 0.53
Nn-10	4.00 ± 0.01	12.66 ± 0.65	28.56 ± 0.18
Nn-11	5.33 ± 0.11	12.66 ± 0.07	23.45 ± 0.07
Nn-12	5.33 ± 0.24	10.66 ± 0.24	22.60 ± 0.50
Nn-13	4.33 ± 0.14	15.00 ± 0.10	23.33 ± 0.81
Nn-14	4.33 ± 0.03	12.66 ± 0.37	23.51 ± 0.94
Nn-15	5.00 ± 0.20	13.00 ± 0.18	22.42 ± 0.07
Nn-16	5.66 ± 0.04	11.33 ± 0.20	23.65 ± 0.33
Nn-17	4.66 ± 0.18	12.66 ± 0.53	22.44 ± 1.14
Nn-18	5.00 ± 0.13	12.33 ± 0.63	25.66 ± 0.41
Nn-19	4.00 ± 0.07	12.00 ± 0.50	27.33 ± 0.89
Nn-20	5.66 ± 0.18	10.67 ± 0.13	28.00 ± 0.51
Nn-21	5.66 ± 0.04	12.00 ± 0.49	25.66 ± 0.72
Nn-22	6.66 ± 0.29	13.33 ± 0.07	31.33 ± 0.64
Nn-23	4.66 ± 0.10	12.00 ± 0.12	29.66 ± 0.55
Nn-24	5.33 ± 0.26	11.66 ± 0.09	29.00 ± 1.01
Nn-25	5.00 ± 0.26	11.66 ± 0.59	30.00 ± 1.40
Nn-26	5.33 ± 0.14	12.66 ± 0.52	23.66 ± 0.05
Nn-27	5.33 ± 0.17	13.33 ± 0.40	22.96 ± 0.90
Nn-28	4.66 ± 0.00	13.00 ± 0.55	26.33 ± 0.49
Nn-29	5.66 ± 0.25	12.00 ± 0.62	28.66 ± 1.00
Nn-30	7.74 ± 2.50	14.79 ± 2.18	15.24 ± 4.20
Max	7.74	15.00	31.33
Min	4.00	10.33	15.24
Range	3.74	4.66	16.09
Mean	5.132	12.234	24.929
S. E	0.108	0.140	0.403
CD 5 %	1.368	1.570	2.989
CV %	16.326	7.859	7.341

Table 3. No. of leaves at weekly intervals (NL)- Week (W)

Acc. No	NL-2W	NL-4W	NL-6W	NL-8W	NL-10W	NL-12W	NL-14W	NL-16W
Nn-1	5.43 ± 0.25	9.20 ± 0.38	12.00 ± 0.40	19.67 ± 0.56	22.40 ± 0.56	26.32 ± 0.01	29.24 ± 0.04	30.11 ± 0.26
Nn-2	6.21 ± 0.31	9.03 ± 0.12	18.67 ± 0.50	19.33 ± 0.28	27.00 ± 0.81	37.41 ± 1.49	41.54 ± 1.36	43.49 ± 0.19
Nn-3	5.87 ± 0.25	9.97 ± 0.16	15.67 ± 0.75	20.33 ± 0.15	26.00 ± 0.05	31.04 ± 0.12	34.07 ± 1.23	35.38 ± 0.72
Nn-4	4.32 ± 0.13	8.45 ± 0.00	17.67 ± 0.10	19.00 ± 0.51	25.00 ± 0.10	32.32 ± 0.32	35.64 ± 1.75	36.83 ± 1.45
Nn-5	5.11 ± 0.27	9.39 ± 0.17	15.33 ± 0.01	21.00 ± 0.03	25.00 ± 0.71	32.10 ± 0.40	36.12 ± 1.54	38.43 ± 1.55
Nn-6	4.76 ± 0.03	9.65 ± 0.25	17.33 ± 0.08	22.00 ± 0.90	26.00 ± 0.22	33.45 ± 1.37	37.55 ± 0.78	39.56 ± 0.80
Nn-7	6.32 ± 0.01	10.20 ± 0.31	14.67 ± 0.14	20.67 ± 0.64	24.50 ± 1.15	30.32 ± 0.03	33.72 ± 0.36	34.16 ± 0.68
Nn-8	4.88 ± 0.07	8.70 ± 0.06	16.33 ± 0.82	22.00 ± 0.89	26.50 ± 0.40	32.32 ± 0.64	36.23 ± 0.67	38.12 ± 0.71
Nn-9	4.32 ± 0.13	8.53 ± 0.07	15.67 ± 0.67	20.67 ± 0.17	25.00 ± 1.26	30.43 ± 1.34	35.52 ± 0.68	37.04 ± 0.99
Nn-10	3.87 ± 0.05	8.68 ± 0.27	14.00 ± 0.37	21.67 ± 0.32	26.60 ± 0.84	33.43 ± 0.31	36.23 ± 0.61	37.98 ± 0.14
Nn-11	5.00 ± 0.11	9.00 ± 0.36	14.33 ± 0.29	21.33 ± 0.13	27.90 ± 0.91	34.43 ± 1.75	37.64 ± 1.29	40.56 ± 2.11
Nn-12	6.21 ± 0.31	10.03 ± 0.50	15.00 ± 0.51	21.00 ± 0.63	28.00 ± 0.86	32.43 ± 0.64	36.12 ± 0.62	37.45 ± 0.10
Nn-13	3.89 ± 0.20	8.42 ± 0.41	13.33 ± 0.35	22.67 ± 0.93	28.00 ± 0.08	34.62 ± 0.50	38.04 ± 1.54	39.09 ± 0.72
Nn-14	4.87 ± 0.22	9.33 ± 0.39	14.33 ± 0.68	24.67 ± 0.37	27.60 ± 0.22	35.34 ± 1.55	39.00 ± 1.60	40.51 ± 0.53
Nn-15	4.98 ± 0.06	9.61 ± 0.31	14.67 ± 0.44	22.67 ± 0.78	28.60 ± 1.43	34.76 ± 0.99	37.31 ± 0.59	39.42 ± 0.71
Nn-16	6.32 ± 0.15	10.10 ± 0.48	16.33 ± 0.63	22.33 ± 0.63	28.70 ± 1.04	34.89 ± 0.28	39.87 ± 1.09	40.65 ± 0.05
Nn-17	3.89 ± 0.02	8.84 ± 0.25	15.00 ± 0.39	21.33 ± 0.83	27.00 ± 1.28	33.76 ± 1.03	37.53 ± 1.79	39.78 ± 0.27
Nn-18	4.32 ± 0.04	8.56 ± 0.06	15.33 ± 0.09	20.67 ± 0.71	25.60 ± 0.50	32.54 ± 1.48	35.97 ± 0.70	37.36 ± 0.15
Nn-19	4.11 ± 0.03	8.65 ± 0.04	13.67 ± 0.28	21.00 ± 0.93	27.40 ± 0.33	33.89 ± 1.57	36.73 ± 1.59	37.89 ± 0.39
Nn-20	6.87 ± 0.20	12.49 ± 0.57	18.00 ± 0.14	20.67 ± 0.91	24.60 ± 0.36	30.45 ± 0.04	34.04 ± 0.18	36.78 ± 0.29
Nn-21	4.70 ± 0.20	9.00 ± 0.30	15.33 ± 0.41	22.67 ± 0.29	27.00 ± 0.85	33.76 ± 0.92	37.14 ± 1.85	39.47 ± 1.39
Nn-22	4.00 ± 0.08	8.03 ± 0.00	14.33 ± 0.25	20.33 ± 0.21	25.70 ± 0.03	32.34 ± 1.33	35.12 ± 0.50	36.94 ± 0.44
Nn-23	4.20 ± 0.12	8.97 ± 0.21	15.33 ± 0.17	21.33 ± 0.56	26.80 ± 0.37	32.40 ± 0.51	36.81 ± 1.11	38.92 ± 1.56
Nn-24	3.98 ± 0.15	9.00 ± 0.04	15.67 ± 0.76	21.67 ± 0.07	27.80 ± 0.54	33.98 ± 0.20	36.42 ± 0.84	37.94 ± 1.42
Nn-25	5.78 ± 0.16	10.07 ± 0.50	16.00 ± 0.80	21.67 ± 0.24	27.00 ± 0.68	34.67 ± 0.77	37.94 ± 0.77	39.47 ± 1.90
Nn-26	5.76 ± 0.29	9.70 ± 0.18	15.00 ± 0.17	22.67 ± 0.98	28.50 ± 0.99	33.54 ± 0.71	37.34 ± 0.95	38.34 ± 0.19
Nn-27	4.32 ± 0.08	8.77 ± 0.38	14.33 ± 0.44	21.33 ± 0.90	25.00 ± 1.03	31.43 ± 1.07	34.57 ± 0.14	37.67 ± 0.64
Nn-28	4.50 ± 0.15	9.03 ± 0.19	15.67 ± 0.58	21.00 ± 0.45	26.70 ± 1.26	32.43 ± 1.27	36.84 ± 1.33	38.89 ± 1.03
Nn-29	3.98 ± 0.13	8.50 ± 0.22	14.00 ± 0.49	21.67 ± 0.58	27.70 ± 0.91	33.43 ± 0.26	37.00 ± 0.82	39.34 ± 0.27
Nn-30	9.83 ± 2.43	15.30 ± 2.33	21.25 ± 2.25	26.55 ± 2.99	32.93 ± 1.35	41.30 ± 2.34	42.74 ± 1.88	34.57 ± 10.76
Max	9.83	15.30	21.25	26.55	32.93	41.30	42.74	44.57
Min	3.89	8.03	13.33	19.00	22.40	26.32	29.24	30.11
Range	5.94	7.27	7.29	7.55	10.53	14.98	13.5	14.46
Mean	5.086	9.440	15.474	21.519	26.751	33.184	36.667	38.071
S. E	0.148	0.164	0.207	0.196	0.229	0.305	0.305	0.410
CD 5 %	1.339	1.454	1.741	2.299	2.317	2.913	3.211	6.142
CV %	16.119	9.432	6.891	6.542	5.303	5.376	5.362	9.878

Table 4. Flowering parameters, Days taken for flower bud emergence (FB), No. of buds per plant (NB), Matured bud weight (MBW), Days for bud to flower (DBF), Field life (FL), No. of rhizome (NR)

Acc. No	FB	NBP	MBW	DBF	FD	FL	NR
Nn-1	57.34 ± 2.07	8.33 ± 0.02	30.00 ± 1.47	12.46 ± 0.47	14.20 ± 0.17	4.66 ± 0.14	4.00 ± 0.16
Nn-2	38.46 ± 0.16	20.66 ± 0.60	12.11 ± 0.46	10.43 ± 0.45	9.60 ± 0.42	3.33 ± 0.09	7.00 ± 0.07
Nn-3	49.54 ± 2.31	6.33 ± 0.27	32.00 ± 1.02	13.45 ± 0.32	14.00 ± 0.53	4.00 ± 0.09	5.00 ± 0.12
Nn-4	69.76 ± 1.80	7.00 ± 0.08	32.43 ± 0.04	12.34 ± 0.46	16.30 ± 0.59	5.66 ± 0.14	4.00 ± 0.03
Nn-5	57.34 ± 2.39	8.33 ± 0.12	20.45 ± 0.79	12.00 ± 0.32	14.54 ± 0.44	3.76 ± 0.04	3.00 ± 0.11
Nn-6	30.76 ± 0.78	16.00 ± 0.22	22.34 ± 0.43	12.87 ± 0.31	13.70 ± 0.59	4.66 ± 0.06	4.00 ± 0.13
Nn-7	69.67 ± 0.13	5.66 ± 0.21	38.76 ± 0.98	13.24 ± 0.31	16.50 ± 0.34	4.12 ± 0.07	5.00 ± 0.16
Nn-8	46.43 ± 1.95	8.16 ± 0.11	31.65 ± 1.55	13.26 ± 0.25	15.50 ± 0.18	4.24 ± 0.03	4.00 ± 0.17
Nn-9	71.87 ± 0.93	8.33 ± 0.03	35.47 ± 0.03	14.65 ± 0.61	16.80 ± 0.16	4.67 ± 0.01	3.00 ± 0.08
Nn-10	73.34 ± 2.35	6.66 ± 0.23	40.00 ± 0.87	14.34 ± 0.54	14.80 ± 0.64	5.12 ± 0.01	4.00 ± 0.00
Nn-11	74.43 ± 3.69	4.33 ± 0.14	42.43 ± 0.30	13.96 ± 0.52	16.70 ± 0.60	4.66 ± 0.00	4.00 ± 0.18
Nn-12	69.34 ± 2.61	6.42 ± 0.15	32.23 ± 1.32	13.28 ± 0.20	15.00 ± 0.03	3.33 ± 0.02	4.00 ± 0.06
Nn-13	41.45 ± 1.29	12.33 ± 0.44	20.23 ± 0.78	11.23 ± 0.25	13.00 ± 0.61	3.66 ± 0.04	6.00 ± 0.15
Nn-14	74.65 ± 3.71	6.66 ± 0.02	37.87 ± 0.71	13.87 ± 0.56	14.20 ± 0.22	3.66 ± 0.14	5.00 ± 0.05
Nn-15	49.54 ± 0.16	7.00 ± 0.32	18.43 ± 0.04	12.87 ± 0.39	13.60 ± 0.46	2.66 ± 0.03	4.00 ± 0.20
Nn-16	37.76 ± 0.53	11.66 ± 0.42	20.56 ± 0.28	12.76 ± 0.13	14.20 ± 0.03	3.33 ± 0.16	7.00 ± 0.01
Nn-17	63.24 ± 3.07	9.56 ± 0.17	28.76 ± 0.27	13.43 ± 0.13	14.90 ± 0.05	4.39 ± 0.19	5.00 ± 0.21
Nn-18	50.32 ± 2.23	8.67 ± 0.14	30.34 ± 0.79	14.76 ± 0.31	16.20 ± 0.53	4.33 ± 0.14	6.00 ± 0.07
Nn-19	54.67 ± 1.66	7.33 ± 0.02	27.45 ± 1.14	14.32 ± 0.42	15.40 ± 0.73	3.89 ± 0.11	4.00 ± 0.18
Nn-20	68.63 ± 2.16	8.66 ± 0.26	29.85 ± 1.42	15.68 ± 0.19	15.20 ± 0.30	4.66 ± 0.00	4.00 ± 0.10
Nn-21	65.43 ± 2.83	7.33 ± 0.03	27.54 ± 0.45	13.87 ± 0.65	13.50 ± 0.30	3.78 ± 0.14	5.00 ± 0.04
Nn-22	79.45 ± 4.01	4.23 ± 0.21	40.54 ± 0.85	15.98 ± 0.41	15.60 ± 0.07	5.98 ± 0.08	3.00 ± 0.13
Nn-23	66.45 ± 0.30	7.66 ± 0.18	42.50 ± 2.04	15.20 ± 0.57	16.00 ± 0.19	5.23 ± 0.12	4.00 ± 0.07
Nn-24	70.43 ± 0.15	6.98 ± 0.06	39.34 ± 1.27	14.76 ± 0.15	14.50 ± 0.53	4.67 ± 0.03	4.00 ± 0.03
Nn-25	69.41 ± 2.33	6.54 ± 0.05	35.64 ± 0.04	15.46 ± 0.13	16.20 ± 0.63	4.33 ± 0.17	4.00 ± 0.07
Nn-26	45.32 ± 1.21	10.33 ± 0.04	22.86 ± 1.11	12.76 ± 0.03	12.60 ± 0.51	3.27 ± 0.07	6.00 ± 0.23
Nn-27	54.43 ± 1.81	8.76 ± 0.31	20.54 ± 0.17	13.67 ± 0.20	14.60 ± 0.70	3.78 ± 0.00	4.00 ± 0.05
Nn-28	60.00 ± 0.22	6.56 ± 0.14	27.44 ± 0.68	14.66 ± 0.58	15.20 ± 0.44	3.87 ± 0.13	4.00 ± 0.08
Nn-29	67.45 ± 2.15	5.33 ± 0.13	37.76 ± 0.83	15.32 ± 0.17	15.70 ± 0.67	4.11 ± 0.06	3.00 ± 0.13
Nn-30	39.31 ± 10.13	15.98 ± 2.61	11.83 ± 0.70	7.66 ± 2.52	9.59 ± 0.69	5.72 ± 2.71	8.00 ± 0.16
Max	79.45	16.00	42.50	15.98	16.80	5.98	8.00
Min	30.76	4.23	11.83	7.66	9.59	3.27	3.00
Range	48.69	11.77	30.67	8.32	7.21	2.71	5.00
Mean	58.847	8.592	29.644	13.484	14.594	4.250	4.566
S. E	1.447	0.383	0.910	0.198	0.194	0.111	0.131
CD 5 %	7.817	1.486	2.580	1.685	1.318	1.425	0.349
CV %	8.130	10.592	5.330	7.654	5.531	20.528	4.688

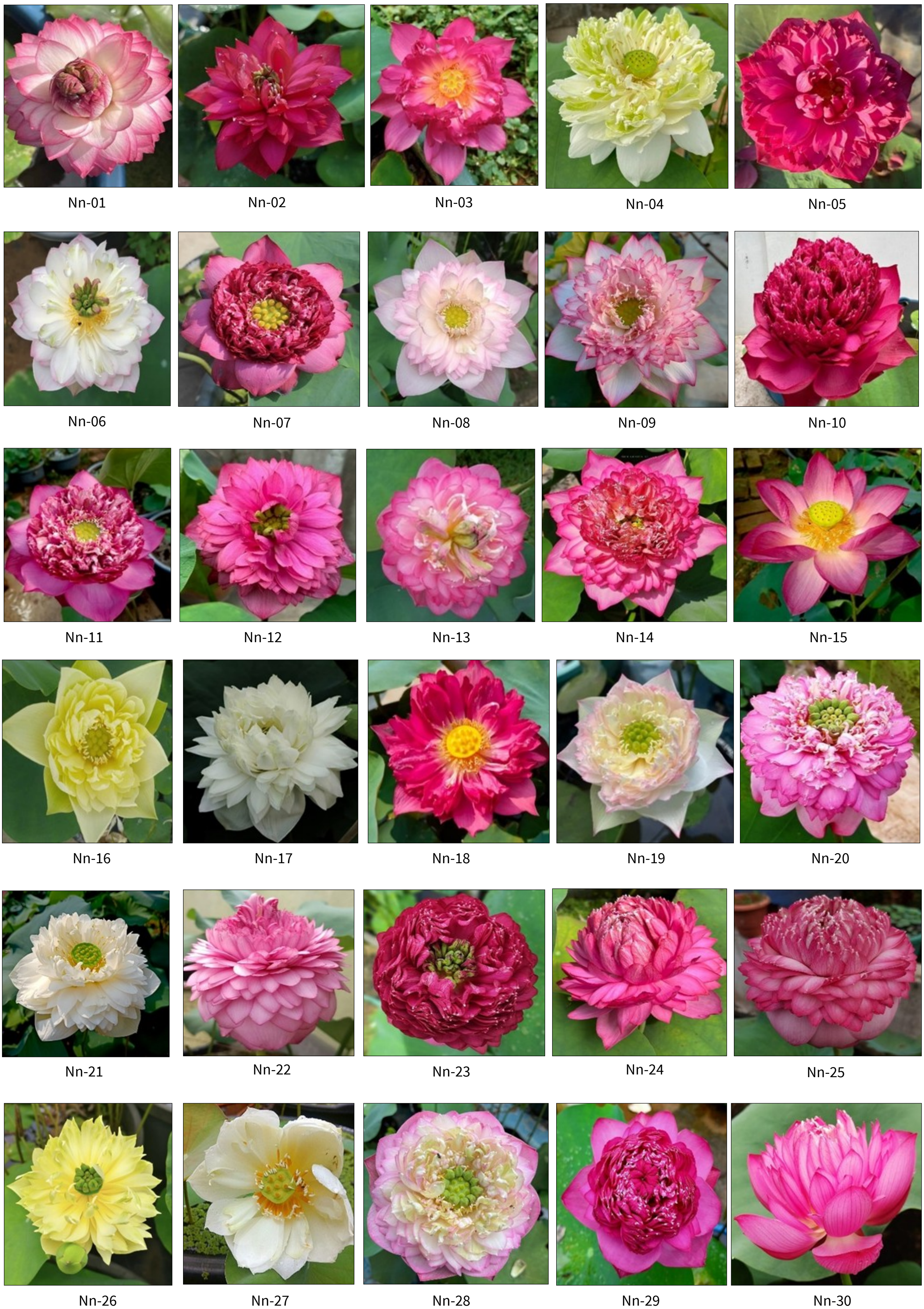

Fig. 1. *Nelumbo nucifera* genotypes used for the study.

Discussion

The results of this study provide valuable insights into the comparative performance of diverse *Nelumbo nucifera* genotypes under standardized growing conditions. The significant variation observed in establishment rate, vegetative growth, rhizome development and flowering traits underscores the importance of evidence-based cultivar selection for optimizing lotus use in aquatic gardens and ornamental landscapes. These findings align with the growing recognition of lotus as not only a culturally symbolic plant but also a versatile horticultural asset (5, 6).

Growth characteristics and garden applications

The genotypes Nn-1, Nn-2, Nn-3, Nn-6, Nn-13 and Nn-30 demonstrated rapid establishment, compact growth and lesser plant height. These traits make them ideal for container gardens, small ponds and mini water features or urban areas where space is limited. Their moderate rhizome growth reduces the need for frequent maintenance, making them a good choice for both home gardeners and nursery growers. These types are grouped as small-sized cultivars (Table 5). This matches recent research showing that compact lotus varieties are well-suited for small or space-limited water gardens (8). The genotypes Nn-28 and Nn-29 grow taller and spread more vigorously. These large cultivars are better suited for large ponds or natural water bodies (2). Research indicates that these large cultivars, with their wide rhizome growth, perform well in open water but can be harder to manage in small or confined water features (2). Meanwhile, cultivars such as Nn-5, Nn-7, Nn-8, Nn -12, Nn-15, Nn-16, Nn-17, Nn-18, Nn-19, Nn-23, Nn-24, Nn-26 and Nn -27 showed intermediate growth traits. These medium-sized cultivars strike a balance between ornamental appeal and manageable growth, making them ideal for medium-sized garden ponds or public landscapes. Their reliable flowering and adaptability make them strong candidates for use in mixed aquatic planting schemes and the value of multifunctional aquatic plants in urban ecological design (7, 9).

Flowering performance

The excellent flowering performance of Nn-6, Nn-16 and Nn-2-characterized by early blooming, a high number of flowers and a long flowering period-makes them highly valuable for ornamental water gardens. These cultivars not only add strong visual appeal but also provide consistent seasonal beauty, which fits well with the goals of modern landscape design (10). Genotypes like Nn-4 and Nn-9, known for their colour-changing flowers and Nn-22 and Nn-23, with their showy double blooms, bring a unique charm to water gardens. Although they may produce fewer flowers, their detailed flower structure and colours offer lasting interest, making them ideal for aquatic gardens and landscaping (5, 11). Late flowering cultivars such as Nn-22, Nn-11 and Nn-10 also have a special role. When planted together with early-flowering types, they extend the overall flowering period. This creates a more vibrant and long-lasting aquatic display, supporting the idea of continuous flowering in garden planning (12).

Environmental adaptability and gardening recommendations

Environmental variability during the study period, particularly in the mid-July heatwave (water temperatures exceeding 30 °C for five days), allowed for the evaluation of stress tolerance among genotypes. Cultivars such as Nn-4, Nn-8, Nn-14, Nn-21 and Nn-28 showed tolerance to heat, maintaining healthy foliage and uninterrupted flowering even under high temperatures, indicating

Table 5. Plant height (PH) at 30, 60 and 90 days after planting

A.cc. No	PH30	PH60	PH90
Nn-1	15.00 ± 0.49	35.80 ± 0.98	50.50 ± 0.79
Nn-2	9.20 ± 0.38	27.50 ± 0.30	34.00 ± 0.87
Nn-3	13.50 ± 0.32	47.50 ± 1.21	60.00 ± 2.25
Nn-4	20.40 ± 0.43	60.40 ± 3.12	87.00 ± 1.59
Nn-5	18.00 ± 0.42	48.00 ± 0.45	69.00 ± 2.20
Nn-6	15.00 ± 0.08	42.40 ± 1.67	58.00 ± 1.63
Nn-7	22.70 ± 1.01	55.70 ± 2.58	76.00 ± 1.46
Nn-8	23.00 ± 0.43	57.80 ± 0.31	72.85 ± 0.72
Nn-9	27.60 ± 0.15	78.90 ± 0.68	92.00 ± 2.00
Nn-10	28.40 ± 0.94	64.60 ± 0.00	98.80 ± 4.36
Nn-11	25.80 ± 0.50	70.60 ± 2.93	102.00 ± 2.65
Nn-12	23.70 ± 0.09	46.80 ± 1.63	79.00 ± 0.05
Nn-13	19.00 ± 0.92	49.70 ± 0.53	57.60 ± 1.91
Nn-14	20.00 ± 0.39	54.60 ± 0.72	87.70 ± 2.23
Nn-15	19.50 ± 0.85	52.30 ± 1.95	78.70 ± 1.05
NN-16	20.20 ± 0.55	56.80 ± 2.58	62.40 ± 0.11
Nn-17	20.00 ± 0.96	53.80 ± 1.89	67.00 ± 2.52
Nn-18	19.50 ± 0.20	68.60 ± 1.71	77.00 ± 3.94
Nn-19	23.00 ± 0.60	52.80 ± 1.61	68.00 ± 0.13
Nn-20	23.50 ± 0.32	78.40 ± 0.03	98.70 ± 2.74
Nn-21	22.00 ± 0.09	68.70 ± 2.04	89.00 ± 3.13
Nn-22	25.90 ± 1.07	70.90 ± 2.24	92.50 ± 3.92
Nn-23	21.40 ± 0.03	67.80 ± 1.20	78.00 ± 0.05
Nn-24	23.60 ± 0.55	57.70 ± 1.44	70.00 ± 2.34
Nn-25	20.40 ± 0.31	68.90 ± 0.28	89.00 ± 1.01
Nn-26	24.80 ± 1.14	53.40 ± 0.19	78.00 ± 0.65
Nn-27	22.30 ± 0.15	52.50 ± 2.51	68.00 ± 2.74
Nn-28	25.80 ± 0.64	50.70 ± 1.10	87.00 ± 0.65
Nn-29	23.90 ± 0.35	48.80 ± 0.83	98.00 ± 0.97
Nn-30	14.04 ± 0.63	18.59 ± 1.16	31.36 ± 11.23
Max	28.40	78.90	102.00
Min	9.20	18.59	31.36
Range	19.20	60.31	70.64
Mean	21.038	55.366	75.236
S. E	0.467	1.438	1.913
CD 5 %	1.669	4.513	8.254
CV %	4.859	4.991	6.717

suitability for hot climates and relevance under projected increases in heatwave frequency due to climate change (IPCC, 2023). Their heat tolerance capacity makes them suitable for hot climates or water gardens without temperature control mechanisms (13).

Nn-7, Nn-22 and Nn-11 showed scorching of leaves and stopped flowering for a short time during the heat, but recovered quickly when it cooled down. This means they may need some extra care, like partial shading, during very hot weather (14). Our study also found that water depth plays an important role in lotus growth. Although all plants were grown at 20 cm depth, small and intermediate cultivars performed well in shallow water (15-20 cm), while large cultivars preferred a little deeper water (25-35 cm). Research indicates that matching water depth to the cultivar improves growth and flowering (15).

This study highlights the considerable variation among the lotus genotypes in response to environmental conditions and cultivation practices. The findings show that growers need to choose the right lotus cultivars for their specific garden use, water body size and local climate. More people are interested in making sustainable and beautiful aquatic gardens. This research helps the growers, nursery professionals and landscape designers make better choices when selecting lotus plants for gardening. Good plant selection leads to healthier plants and more beautiful gardens.

Conclusion

This evaluation of lotus genotypes reveals significant differences in growth and flowering characteristics that are directly relevant to their ornamental value and garden applications. Based on our findings, we make the following recommendations for aquatic garden practitioners. For small water features or container gardens, Nn-2, Nn-6, Nn-30 and Nn-13 offer ideal combinations of compact growth and reliable flowering. For medium to large water gardens seeking maximum flowering impact, Nn-22, Nn-23 and Nn -4 provide exceptional performance through large-sized bloom production and extended field life. For creating diverse visual interest through flower form and colour variation, Nn-4, Nn-23 (double flowers) and Nn-22 (Thousand petaled) offer unique ornamental qualities despite their more moderate flowering quantity. For extending the blooming period of water gardens, combining early-flowering cultivars (Nn-6, Nn-16 and Nn-2) with later-blooming types (Nn-22, Nn-10, Nn-11 and Nn-24) can provide continuous visual interest throughout the growing season. For regions with high summer temperatures, Nn-4, Nn-8, Nn-14, Nn-21 and Nn-28 demonstrate superior heat tolerance and consistent performance. The findings of this study highlight the untapped potential of diverse lotus genotypes for enhancing aquatic gardens and demonstrate the value of evidence-based selection when incorporating these elite aquatic plants into designed landscapes.

Limitations and Future Research Directions

This study gives useful information for comparing lotus genotypes. However, there are some limitations to consider. The usage of plastic containers, which may not be the same as natural ponds or large water features. This was long enough to see how the plants performed at the early stage. But it may not show how the plants grow over many years or if they decline after several seasons. Future research may test these lotus types and others under different conditions. Scientists can try different water depths, soil types and nutrient levels. Researchers need to study how plant genetics and the environment work together. This is especially important because of climate change. Gardens need plants that can handle changing conditions. Scientists can also study the genes that cause the differences between lotus types. This information could help plant breeders create new lotus varieties. These enhanced varieties could combine superior traits with greater environmental adaptability.

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Authors' contributions

GP and SA conceptualized the study, designed the research framework and coordinated the manuscript preparation. PS contributed to the critical analysis of the horticultural significance of lotus. SK assisted in compiling data on lotus propagation, breeding and agronomic practices. RR provided insights on biochemical and medicinal properties, ensuring a comprehensive discussion. MD supervised the manuscript, refined the content and provided expert guidance on plant physiology and stress tolerance aspects. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflicts of interest to declare.

Ethical issues: None

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