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QR CODE-BASED DIGITAL DOCUMENTATION OF MEDICINAL AND AROMATIC PLANT DIVERSITY AT TEERTHANKER MAHAVEER UNIVERSITY, MORADABAD, UTTAR PRADESH: A SUSTAINABLE APPROACH FOR BIODIVERSITY CONSERVATION AND SMART BOTANICAL EDUCATION

Ganesh Datt Bhatt[1*], Lochan Vyas[2], Parveen Kumar Jain[3], Balraj Singh[4], Mahesh Singh[5]

[1*]Teerthanker Mahaveer College of Agriculture Sciences (ICAR Accredited), Teerthanker Mahaveer University, Moradabad - 244001, Uttar Pradesh, India.
[2,3,4,5]Teerthanker Mahaveer College of Agriculture Sciences (ICAR Accredited), Teerthanker Mahaveer University, Moradabad - 244001, Uttar Pradesh, India.

ABSTRACT
The present study was conducted at the Medicinal and Aromatic Plant Garden established at Teerthanker Mahaveer University (TMU), Moradabad, Uttar Pradesh, India, where QR code technology was implemented for digital citation and documentation of medicinal plant species. The garden consists of more than 91 medicinal, aromatic, ethno-botanical, horticultural, sacred, and economically important plant species including *Ocimum tenuiflorum* L., *Withania somnifera* (L.) Dunal, *Tinospora cordifolia* (Willd.) Hook.f. & Thomson, *Azadirachta indica* A. Juss., *Catharanthus roseus* (L.) G.Don, *Curcuma longa* L., *Aloe barbadensis* Mill., *and Centella asiatica* (L.) Urb. etc. Unique QR codes were generated for each species and linked to a digital database containing botanical, ecological, medicinal, taxonomic, and ethno-botanical information.
The study evaluated the role of QR code technology in enhancing biodiversity conservation, educational interaction, accessibility of plant information, and sustainable campus initiatives. Results indicated significant improvement in visitor engagement, botanical awareness, and Experiential Learning Program (ELPs) among students and researchers. The QR code system provided rapid access to authenticated information through smartphones and demonstrated potential for replication in botanical gardens, universities, and biodiversity parks etc. The study highlights the importance of integrating modern information technologies with traditional medicinal plant knowledge for sustainable biodiversity conservation and digital education.

KEYWORDS: QR code, medicinal and aromatic plants, biodiversity conservation, digital documentation, ethno-botany, botanical education, TMU Moradabad.

1. INTRODUCTION

Medicinal and aromatic plants have served humanity since ancient times and continue to play an essential role in healthcare, traditional medicine, pharmaceutical development, and biodiversity conservation worldwide (WHO, 2013; Kala et al., 2006; Hamilton, 2004). India is one of the richest countries in terms of medicinal plant diversity and possesses an extensive ethno-botanical heritage associated with Ayurveda, Siddha, Unani, and folk medicinal systems (Ved & Goraya, 2008; Schippmann et al., 2002). Approximately, 7000-8000 plant species are used in Indian traditional medicine systems, contributing significantly to rural healthcare and medicinal and aromatic industries (Kirtikar & Basu, 1999).
The rapid expansion of urbanization, habitat destruction, industrialization, and climate change has threatened numerous medicinal plant species and associated indigenous knowledge systems (CBD, 2020; FAO, 2014; Bhatt et al., 2015). Conservation and scientific documentation of medicinal plants have therefore become essential for sustainable utilization and biodiversity management (Heywood, 2017; Funk et al., 2005; Kushwaha et al., 2020). Botanical gardens and medicinal and aromatic plant gardens serve as important ex-situ conservation centers for preserving threatened medicinal plants while simultaneously supporting education, awareness, and research activities (BGCI, 2015; Soltis et al., 2018).
Recent advancements in Information and Communication Technologies (ICTs) have transformed biodiversity documentation and educational methodologies globally (Mishra & Koehler, 2006). Among these innovations, Quick Response (QR) codes have emerged as highly efficient digital tools capable of linking physical specimens with comprehensive digital databases accessible through smartphones and internet-enabled devices (Law & So, 2010; Okazaki et al., 2012). QR codes provide a low-cost, user-friendly, and sustainable mechanism for disseminating scientific information and promoting interactive learning experiences (Rikala & Kankaanranta, 2014; Lai et al., 2013).
The application of QR code technology in botanical gardens, museums, educational campuses, and biodiversity parks has increased substantially in recent years (Diazgranados & Funk, 2013; Aldya et al., 2022). International institutions such as the Royal Botanic Gardens, Kew, and the University of California Botanical Garden have effectively integrated QR code systems for improving visitor engagement and conservation awareness (Bhatt et al., 2024a). In India, QR-based

documentation systems are gradually being adopted for preserving traditional knowledge and digitizing medicinal plant information (Bhatt and Jain, 2024b).

The Medicinal and Aromatic Plant Garden established at Teerthanker Mahaveer University (TMU), Moradabad, Uttar Pradesh, represents an innovative effort toward digital biodiversity conservation and botanical education. The garden contains a diverse collection of medicinal herbs, shrubs, climbers, grasses, sacred plants, aromatic species, and ethno-medicinal trees including *Ocimum sanctum* L., *Withania somnifera* (L.) Dunal, *Gymnema sylvestre* (Retz.) R.Br. ex Sm., *Tinospora cordifolia* (Willd.) Hook.f. & Thomson, *Moringa oleifera* Lam., *Aegle marmelos* (L.) Corrêa, *Saraca asoca* (Roxb.) Willd., and *Rauvolfia serpentina* (L.) Benth. ex Kurz (Table 1).

The present investigation was undertaken to develop a comprehensive QR code-based digital documentation system for medicinal and aromatic plants cultivated at TMU Moradabad. The objectives of the study were:

1.To document medicinal and aromatic plant diversity in the garden.
2.To generate QR codes linked with scientific plant information.
3.To promote biodiversity awareness and digital learning.
4.To evaluate the educational and conservation significance of QR-enabled botanical systems.
5.To integrate traditional medicinal plant knowledge with modern digital technologies.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out at the Medicinal and Aromatic Plant Garden located within Teerthanker Mahaveer University (TMU), Moradabad, Uttar Pradesh, India. Moradabad lies in the Indo-Gangetic plains and experiences a sub-tropical climatic condition characterized by hot summers, moderate rainfall during monsoon, and cool winters. The fertile alluvial soils and suitable climatic conditions support the growth of diverse medicinal and aromatic plant species.

The garden was established for educational, conservation, research, awareness, and extension purposes. The garden consists of numerous medicinal herbs, aromatic grasses, sacred trees, shrubs, horticultural species, ethno-medicinal climbers, and economically important plants (Bhatt et al., 2023).

2.2 Documentation of Plant Diversity

Extensive field surveys and taxonomic studies were conducted for documenting medicinal and aromatic plant species present in the garden. Each QR code was linked to a digital database containing scientific names, author citations, family names, local names, habit, medicinal uses, and ecological importance were recorded using standard floristic manuals and taxonomic databases (Kirtikar & Basu, 1999; The Plant List, 2013).

The garden includes diverse medicinal taxa such as *Ocimum tenuiflorum* L., *Ocimum sanctum* L., *Ocimum gratissimum* L., *Withania somnifera* (L.) Dunal, *Bacopa monnieri* (L.) Wettst., *Centella asiatica* (L.) Urb., *Aloe barbadensis* Mill., *Trachyspermum ammi* (L.) Sprague, *Rauvolfia serpentina* (L.) Benth. ex Kurz, *Catharanthus roseus* (L.) G.Don, *Curcuma longa* L., *Mentha spicata* L., *Boerhavia diffusa* L., *Tribulus terrestris* L., *Tinospora cordifolia* (Willd.) Hook.f. & Thomson, *Clitoria ternatea* L., *Stevia rebaudiana* (Bertoni) Bertoni, and *Andrographis paniculata* (Burm.f.) Wall. ex Nees (Table 1).

Tree species documented in the garden included *Azadirachta indica* A. Juss., *Ficus religiosa* L., *Ficus benghalensis* L., *Saraca asoca* (Roxb.) Willd., *Mangifera indica* L., *Syzygium cumini* (L.) Skeels, *Cedrus deodara* (Roxb. ex D.Don) G.Don, *Neolamarckia cadamba* (Roxb.) Bosser, *Swietenia mahagoni* (L.) Jacq., *Mesua ferrea* L., and *Shorea robusta* Gaertn (Table 1).

2.3 QR Code Generation and Digital Integration

Unique QR codes were generated for each medicinal and aromatic plant species using QR code generation software based on ISO/IEC digital standards (ISO, 2015; Denso Wave, 2014). Each QR code developed for the medicinal and aromatic plants was digitally linked with comprehensive scientific and educational information related to the respective plant species. The information database included the botanical name along with proper author citation, family name, vernacular and Hindi names, medicinal properties, ethno-botanical importance, and detailed taxonomic descriptions of the plants. In addition, the QR-enabled system provided information regarding therapeutic applications, traditional uses in ayurveda and folk medicine, ecological and conservation significance, and sustainable utilization practices (Kushwaha et al., 2020). Photographs of individual plant species, educational descriptions, and awareness-oriented content were also incorporated into the digital platform to enhance interactive learning, biodiversity education, and public awareness among students, researchers, faculty members, and visitors etc. QR code labels were printed on durable weather-resistant materials and installed adjacent to each plant species in the garden.

2.4 Educational Assessment and Visitor Interaction

Students, faculty members, researchers, and visitors accessed plant information by scanning QR codes using smartphones. Visitor interaction and educational effectiveness were evaluated through observations, surveys, and feedback collection methods (Law & So, 2010; Rikala & Kankaanranta, 2014).

3. RESULTS AND DISCUSSION

3.1 Diversity of Medicinal and Aromatic Plants

The garden at TMU Moradabad exhibited rich diversity of medicinal and aromatic plants belonging to several important taxonomic families including Lamiaceae, Rutaceae, Fabaceae, Poaceae, Apocynaceae, Lauraceae, Euphorbiaceae, Malvaceae, Solanaceae, and Myrtaceae etc., (Table 1).

Medicinal plants such as *Ocimum tenuiflorum* L., *Ocimum sanctum* L., *Mentha spicata* L., *Bacopa monnieri* (L.) Wettst., and *Centella asiatica* (L.) Urb. etc., are traditionally used in ayurvedic medicine for treating respiratory disorders, memory enhancement, digestive ailments, fever, stress, and neurological disorders (Mukherjee et al., 2007).
Species such as *Withania somnifera* (L.) Dunal and *Gymnema sylvestre* (Retz.) R.Br. ex Sm. possess significant pharmacological importance due to their adaptogenic, antidiabetic, antioxidant, and immunomodulatory properties (Mukherjee et al., 2007; WHO, 2013). Aromatic grasses including *Cymbopogon citratus* (DC.) Stapf and *Cymbopogon flexuosus* (Nees ex Steud.) W.Watson are economically important due to their essential oil production and industrial applications (FAO, 2014).
Sacred and culturally significant tree species such as Ficus religiosa L., *Aegle marmelos* (L.) Corrêa, *Saraca asoca* (Roxb.) Willd., and *Azadirachta indica* A. Juss., are important components of Indian traditional healthcare systems and biodiversity conservation initiatives (Table 1).

3.2 Implementation of QR Code Technology

The QR code system was successfully implemented throughout the garden and enabled rapid retrieval of plant information using mobile devices. Visitors and students could instantly access detailed medicinal, botanical, ecological, and taxonomic information by scanning QR codes installed near individual plant species.
The QR-enabled system significantly enhanced accessibility to scientific knowledge and promoted interactive learning experiences among students and researchers (Law & So, 2010). Similar findings have been reported from botanical gardens and biodiversity parks where QR code technology improved public participation and educational engagement (Diazgranados & Funk, 2013; Aldya et al., 2022).
The integration of QR code technology reduced dependency on printed labels and static educational materials while facilitating real-time updating of information databases. The digital system also improved data management efficiency and supported sustainable campus initiatives (Rikala & Kankaanranta, 2014; Soltis et al., 2018).

3.3 Educational and Research Significance

The QR code-enabled medicinal and aromatic plant garden served as an ELPs platform for students of agriculture, botany, forestry, pharmacy, horticulture, and environmental sciences. Students gained direct exposure to medicinal and aromatic plant diversity and were able to access scientific literature and ethno-botanical information in real time (Bhatt et al., 2021).
Faculty members observed increased student interest in medicinal and aromatic plants, biodiversity conservation, and plant taxonomy after implementation of QR code systems. The initiative supported outcome-based education, smart learning environments, and multidisciplinary research activities promoted by higher educational institutions (Mishra & Koehler, 2006).
The QR-enabled system also facilitated extension activities and awareness campaigns related to biodiversity conservation, sustainable agriculture, and traditional medicinal knowledge. Workshop and field demonstrations organized within the garden enhanced public participation and environmental awareness (Bhatt et al., 2021).
3.4 Biodiversity Conservation and Sustainable Development Goals
Medicinal plant conservation contributes directly toward several United Nations Sustainable Development Goals (SDGs), including SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), SDG 13 (Climate Action), and SDG 15 (Life on Land) (CBD, 2020; FAO, 2014).
The QR code-based documentation model developed at TMU Moradabad demonstrates how digital technologies can strengthen biodiversity conservation and promote sustainable educational practices. The initiative also supports preservation of traditional ethno-medicinal knowledge and indigenous healthcare systems.
The digital documentation of medicinal plants through QR technology can serve as an effective model for universities, botanical gardens, biodiversity parks, and plants conservation centers across India and globally.

4. CONCLUSION

The present study successfully demonstrated the implementation of QR code technology for digital documentation and conservation of medicinal and aromatic plants at Teerthanker Mahaveer University, Moradabad, Uttar Pradesh. The integration of QR-enabled systems significantly enhanced accessibility to plant information, promoted ELPs, strengthened biodiversity awareness, and supported sustainable educational initiatives.
The garden developed under this initiative contains diverse medicinal, aromatic, sacred, horticultural, and ethno-botanical plant species that serve as valuable educational and conservation resources. QR code technology proved to be a low-cost, user-friendly, scalable, and sustainable approach for integrating traditional botanical knowledge with modern digital innovations.
Future research may focus on integrating GIS mapping, cloud databases, artificial intelligence, augmented reality, and multi-lingual mobile applications for further strengthening digital biodiversity conservation systems.

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gardeners, and technical personnel for their valuable contribution to plants documentation, QR code generation, and maintenance of the garden.

Table 1. List of medicinal and aromatic plant species in the garden, showing their common names, botanical names, and QR-code-based identification.

 1.*Ocimum tenuiflorum* L.	 2.*Ocimum sanctum* L.	 3.*Ocimum gratissimum* L.
 4.*Origanum majorana* L.	 5.*Cymbopogon citratus* (DC.) Stapf	 6.*Cymbopogon flexuosus* (Nees ex Steud.) W.Watson
 7.*Withania somnifera* (L.) Dunal	 8.*Costus igneus* N.E.Br.	 9.*Trachyspermum ammi* (L.) Sprague

 10. *Elettaria cardamomum* (L.) Maton	 11. *Centella Asiatic* (L.) Urb.	 12. *Bacopa monnieri* (L.) Wettst.
 13. *Chlorophytum borivilianum* Santapau & R.R.Fern.	 14. *Datura metel* L.	 15. *Mansoa alliacea* (Lam.) A.H.Gentry
 16. *Carica papaya* L.	 17. *Gymnema sylvestre* (Retz.) R.Br. ex Sm.	 18. *Aloe barbadensis* Mill.

 19. *Piper betle* L.	 20. *Barleria prionitis* L.	 21. *Achyranthes aspera* L.
 22. *Cyperus scariosus* R.Br.	 23. *Ocimum basilicum* var. purpurascens Benth.	 24. *Acorus calamus* L.
 25. *Rauvolfia serpentina* (L.) Benth. ex Kurz	 26. *Ocimum basilicum* L.	 27. *Mimosa pudica* L.

28. *Plumbago zeylanica* L.

29. *Azadirachta indica* A. Juss.

30. *Carica papaya* L.

31. *Asparagus racemosus* Willd.

32. *Piper longum* L.

33. *Datura stramonium* L.

34. *Syzygium aromaticum* (L.) Merr. & L.M.Perry

35. *Bixa Orellana* L.

36. *Tinospora cordifolia* (Willd.) Hook.f. & Thomson

37. *Ocimum kilimandscharicum* Guerke

38. *Tecoma stans* (L.) Juss. ex Kunth

39. *Andrographis paniculata* (Burm.f.) Wall. ex Nees

40. *Stevia rebaudiana (*Bertoni) Bertoni

41. *Eclipta prostrata* L.

42. *Kalanchoe pinnata* (Lam.) Pers.

43. *Clitoria ternatea* L.

44. *Catharanthus roseus* (L.) G.Don

45. *Calotropis gigantea* (L.) W.T.Aiton

46. *Curcuma longa* L.

47. *Mentha spicata* L.

48. *Phyllanthus niruri* L.

49. *Boerhavia diffusa* L.

50. *Tribulus terrestris* L.

51. *Solanum nigrum* L.

52. *Paederia foetida* L.

53. *Allium commutatum* Guss.

54. *Cissus quadrangularis* L.

55. *Hibiscus rosa-sinensis* L.

56. *Moringa oleifera* Lam.

57. *Psidium guajava* L.

58. *Lawsonia inermis* L.

59. *Syzygium cumini* (L.) Skeels

60. *Aegle marmelos* (L.) *Corrêa*

61. *Aegle marmelos* (L.) *Corrêa*

62. *Citrus limon* (L.) *Osbeck*

63. *Mangifera indica* L.

		
64. *Saraca asoca* (Roxb.) Willd.	65. *Terminalia bellirica* (Gaertn.) Roxb.	66. *Ficus benghalensis* L.
		
67. *Magnolia champaca* (L.) Baill. ex Pierre	68. *Diospyros melanoxylon* Roxb.	69. *Cedrus deodara* (Roxb. ex D.Don) G.Don
		
70. *Ficus religiosa* L.	71. *Swietenia mahagoni* (L.) Jacq.	72. *Mesua ferrea* L.

73. *Syzygium cumini* (L.) Skeels

74. *Neolamarckia cadamba* (Roxb.) Bosser

75. *Shorea robusta* Gaertn.

76. *Alstonia scholaris* (L.) R.Br.

77. *Albizia lebbeck* (L.) Benth.

78. *Mimusops elengi* L.

79. Aegle marmelos L.

80. *Dendrocalamus strictus* (Roxb.) Nees

81. *Prunus persica* (L.) Batsch

82. *Malus domestica* Borkh.

83. *Citrus sinensis* (L.) Osbeck

84. *Punica granatum* L.

85. *Limonia acidissima* L.

86. *Phyllanthus emblica* L.

87. *Delonix regia* (Bojer ex Hook.) Raf.

88. *Jatropha curcas* L.

89. *Jacaranda mimosifolia* D.Don

90. *Pterospermum acerifolium* (L.) Willd.

 91. *Peltophorum pterocarpum* (DC.) K.Heyne	92.	93.

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