**BIODIVERSITAS**
Volume 26, Number 6, June 2025
Pages: 2735-2745

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260618

# Digitization of rare Balinese (Indonesia) Hindu ritual plants for conservation and biology education

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Manuscript received: 26 March 2025. Revision accepted: 24 May 2025.

**Abstract.** *Sudirgayasa IG, Sulisetijono, Mahanal S, Gofur A, Surata IK, Sudiana IM, Maduriana IM. 2025. Digitization of rare Balinese (Indonesia) Hindu ritual plants for conservation and biology education. Biodiversitas 26: 2735-2745.* Plants hold significant philosophical and symbolic value in the ritual life of the Balinese Hindu community in Indonesia. Various plant species serve as essential components in religious ceremonies and are deeply rooted in local wisdom. However, modernization has led to the decline and fading recognition of some of these ritual plants among younger generations. This study, which adopts an interdisciplinary approach, aims to conserve, and revitalize ethnobotanical knowledge by exploring and digitizing rare Balinese Hindu ritual plants. Data were collected through field exploration, semi-structured interviews, and a literature review. The study successfully identified 56 rare plant species used in Balinese rituals. These species were digitized through a mobile and web-based platform called *Taru Yadnya*, which was also developed as a transdisciplinary biology learning medium grounded in local cultural wisdom. Digitization not only serves conservation purposes but also provides an innovative educational tool to facilitate knowledge transfer across generations. The results of this study are expected to contribute significantly to biodiversity preservation and cultural sustainability efforts in Bali while supporting transformative and contextual biology education.

**Keywords:** Balinese, digitization, education, ethnobotany, rare, ritual plants

## INTRODUCTION

Plants hold philosophical and symbolic significance in the ritual life of Balinese Hindu communities (Sujarwo et al. 2020; Darma et al. 2021; Ratnani et al. 2021; Wijana et al. 2022). These values are manifested in various religious ritual offerings known as *upakara banten*. More than 125 plant species are used in *upakara banten* (Sujarwo et al. 2020). Some of these ritual plant species are highly unique and uncommon. This uniqueness is partly due to genetic variation, as seen in coconut plant varieties such as *nyuh sudamala, nyuh rangda, nyuh be julit, nyuh udang*, and *nyuh bojog* (Kriswiyanti et al. 2013). In addition to their uniqueness, several ritual plants are considered rare, such as sandalwood (*Santalum album*), which is listed as a threatened species on the IUCN Red List of Threatened Species (Arunkumar et al. 2019). Therefore, the conservation of these plants is essential. An initial step toward conservation can be taken by documenting Balinese Hindu ritual plants in internet-based digital media. The next step involves transferring ethnobotanical knowledge of ritual plants to younger generations through the education system.

The documentation of ethnobotanical local wisdom in internet-based digital media is a strategic step to ensure that traditional knowledge remains alive and relevant in the digital era (Carney et al. 2022). By preserving information about plants, their uses, and the cultural contexts of their application in an easily accessible online system, this knowledge is not only protected from the risk of extinction but also made available to researchers, students, and the wider community (Asuquo et al. 2023). This approach enables intergenerational and cross-regional knowledge transfer without geographical limitations while also fostering equitable and respectful collaboration between indigenous communities and the academic world. Furthermore, digitalization strengthens the position of local wisdom as a source of inspiration for the development of science and nature-based innovation (Chitakunye et al. 2023).

The transfer of ethnobotanical knowledge through a transdisciplinary learning approach is a method that integrates various fields of study, such as biology, anthropology, ecology, pharmacy, economics, and the social sciences, with traditional community knowledge regarding the use of plants in daily life (Nieves et al. 2023). This method involves collaboration between academics and local communities to comprehensively examine the interactions between humans and plants (Albuquerque and Alves 2016). In the context of education, this approach not only delivers theoretical biological knowledge about plants but also highlights cultural values, traditions, and local practices related to plant use. As a result, learning becomes more meaningful by combining scientific and local perspectives to better understand the importance of plants in human life.

However, over time, many Balinese Hindu ritual plants have become increasingly rare and less familiar to younger generations (Rinto et al. 2023). Land conversion driven by population growth has led to the shrinking of natural ecosystems where these ritual plants thrive. Climate change and overexploitation have also contributed to their scarcity (Cahyaningsih et al. 2021; Moradi et al. 2025). At the same time, modernization has triggered cultural erosion and lifestyle changes among the youth, resulting in a lack of awareness of ritual plant species (Sujarwo et al. 2014; Dip et al. 2024; Luo et al. 2024). The transmission of knowledge about ritual plants typically occurs orally and through hands-on practice passed down from generation to generation, making it vulnerable to being forgotten (Anbessa et al. 2024; Awoke et al. 2024). The unique and uncommon characteristics of ritual plants are often known only by traditional or religious leaders, placing this knowledge at risk of disappearing once they pass away. In addition, some of the documentation of ritual plants is still in the form of printed media, making it vulnerable to loss due to weathering and disasters (Kandowangko et al. 2018). Previous ethnobotanical studies on ritual plants by Zare et al. (2017), Sutrisno et al. (2020), Rahayu et al. (2023), and Sholekha et al. (2023) have not yet utilized internet-based multimedia and multiplatform formats, limiting their accessibility and reach. In the field of education, the integration of local wisdom remains limited and is often confined to specific subjects (Arjaya et al. 2024). The incorporation of ethnobotanical local wisdom into biology education still applies an intradisciplinary approach within the subject of ethnobotany. If this condition persists, Balinese Hindu ritual plants and their associated local wisdom values may face extinction.

Based on these issues, the digitalization of Balinese Hindu ritual plants must be urgently implemented as an initial step toward conservation. The digitalization outcomes should also be designed to serve as a medium for transdisciplinary biology education. Digitalization is chosen due to several advantages, including more comprehensive, engaging, and long-lasting documentation; broader and easier access; increased opportunities for collaboration among communities, government, and industry stakeholders; and more attractive, interactive, and meaningful educational media (Redweik et al. 2023; Guo et al. 2024). Therefore, this study aims to: (i) explore and identify Balinese Hindu ritual plants that are classified as Rare; (ii) digitize the ethnobotanical data of these plants into an internet-based, multiplatform digital medium; (iii) design the digitalization output as a transdisciplinary biology learning resource grounded in local wisdom.

## MATERIALS AND METHODS

### Study area

Data collection for this study was conducted across the entire Province of Bali, Indonesia, which consists of eight regencies and one city (Figure 1). The Province of Bali covers an area of 5,780.06 square kilometers and has a population of 4,461,270 people. The red dots (60) on the map indicate the location of the exploration of rare plants used in Balinese Hindu rituals. The exploration sites were determined based on informant guidance through purposive sampling methods.

### Procedures

This study employed an exploratory research method and was conducted over six months, from July 2023 to December 2023. The procedures for data collection and digitalization are outlined below.

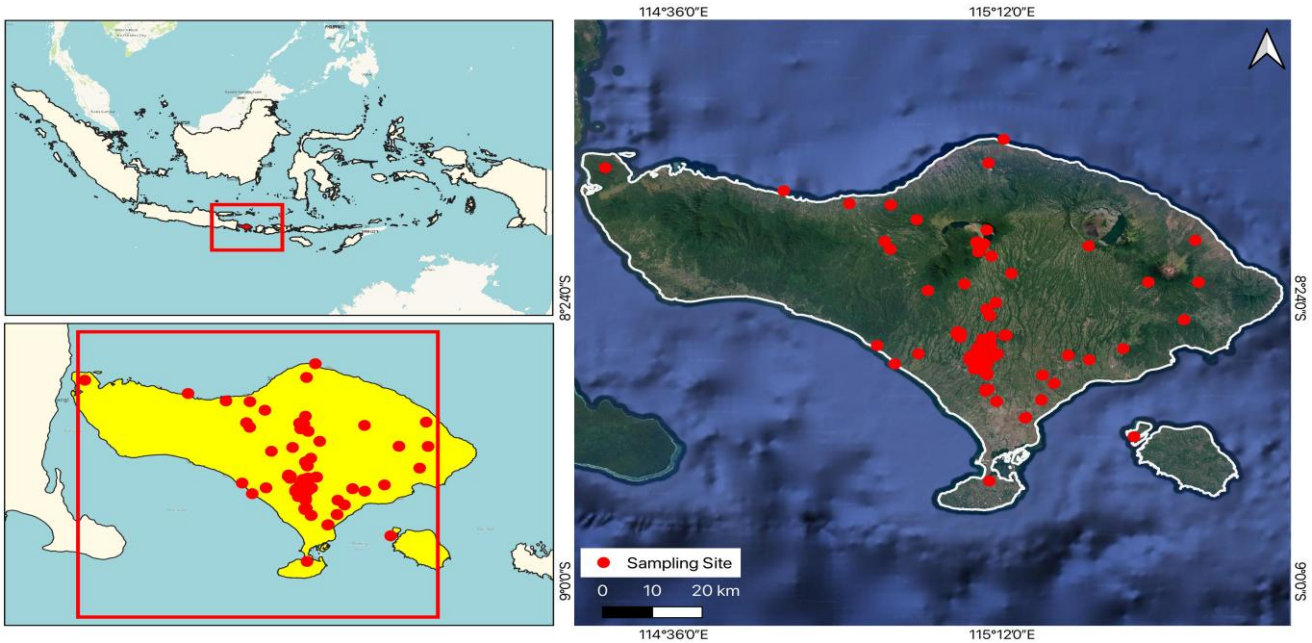


**Figure 1.** Map of exploration location in Bali Province, Indonesia

*Data collection*

Data on diversity of Balinese Hindu ritual plants were collected through interviews and field observations, then digitized. Interviews were conducted to collect ethnobotanical data and location information on Balinese Hindu ritual plants. Primary informants were selected using purposive sampling, with representatives from the Indonesian Hindu Dharma Council or *Parisada Hindu Dharma Indonesia* (PHDI) in each district and city. Based on the guidance of these primary informants, recommended and key informants were identified through snowball sampling until thematic redundancy and data saturation were reached, when the collected ethnobotanical information no longer yielded significant new insights. The selected informants consisted of religious leaders and *Serati*, individuals who are skilled in preparing Balinese Hindu ritual offerings. The minimum informants were nine religious leaders and nine *Serati*, representing each district and city in the Province of Bali. The questions asked include: (i) local names, (ii) parts used, and (iii) ritual use. In addition to ethnobotanical data, several questions were designed to confirm the rarity status of Hindu Balinese ritual plants, such as: (i) Is this plant still easy to find today? If so, where? (ii) In your opinion, has the population of this plant declined? Since when? (iii) What are the main causes of its rarity, in your view? Meanwhile, plant identification and scientific names refer to IPNI (www.ipni.org) and POWO (https://powo.science.kew.org).

Data were also collected through both in situ and ex situ participant observations. In situ observations were aimed at gathering data on the identity, morphology, and distribution locations of the plants. Ex situ observations were conducted to collect ethnobotanical data, including local names, plant parts used, and examples of their applications. Interview results with informants from each district and city guided observations.

In situ observations focused on identifying at least one species or variety of Balinese Hindu ritual plants classified as rare. The confirmation of the rarity status of Hindu Balinese ritual plants was also conducted through direct field observations of the condition and presence of the plants in their natural habitats. These observations included recording the number of individual plants, the extent of their distribution area, habitat conditions, and their frequency of occurrence at selected sampling points. We also provide an opportunity for the general public to contribute additional data on plant identity and distribution through a designated Google Form link, thereby ensuring the continuous growth of our database and fostering a sense of community.

The literature review was conducted to gain a preliminary understanding of the topic and to support the strategies for observation, interviews, and digitalization. It also served as a reference during the data analysis process (Albuquerque et al. 2017). Priority was given to literature sourced from scientific journal articles, books, and relevant research findings. We meticulously sourced journal articles with all references obtained from Scopus-indexed journals, instilling confidence in our research process. All necessary literature is mentioned in the references. Additionally, the rarity status of Hindu Balinese ritual plants was confirmed through document analysis by examining and analyzing various written sources containing information on the presence, distribution, and conservation status of these plants. The documents utilized included the IUCN Red List, as well as regulations issued by national and local governments.

*Data digitization*

Plant data obtained from observations, interviews, and literature review were stored in digital media formats, including a website and a mobile application. The digital website was developed using Google Sites, while the mobile application was created using WebToNative in Android App Bundle (AAB) format, making it downloadable via the Google Play Store. These digital platforms are accessible to the public via a laptop, tablet computer, or smartphone anytime and anywhere. Additionally, the digital media were designed to serve as transdisciplinary biology learning tools through the inclusion of a "Student Project" menu, which contains instructional materials for both lecturers and students.

**Data analysis**

The analysis of plant rarity levels is categorized into three tiers: local, national, and international. Local rarity is determined based on Bali Governor Regulation Number 29 of 2020 (Pergub Bali No. 29/2020) about “Conservation of local plants in Bali as *Gumi Banten Park, Puspa Dewata, Usada*, and greening”, where in its considerations it is stated that these plants are "increasingly rare and threatened with extinction", reinforced by interviews with traditional leaders and *Serati* as direct users, as well as field observation. National rarity is determined based on the Indonesian Ministry of Environment and Forestry Regulation Number P.92/MENLHK/SETJEN/KUM.1/8/2018, about “Protected Plant and Animal Species”. International rarity is determined based on the IUCN Red List Categories and Criteria (www.iucn.org).

## RESULTS AND DISCUSSION

**Distribution data of rare Balinese Hindu ritual plants**

The mapping of plant distribution began with in situ observations based on a literature review and interviews with informants. A total of 205 Balinese Hindu ritual plants were observed, of which 56 were classified as rare. The locations of each plant were recorded using the Google Maps application. The coordinates were then imported into Google My Maps and Google Earth to generate a visual distribution map (Figure 2). The observed plant distributions are located in the regencies of Tabanan, Gianyar, Badung, and Buleleng. This distribution map will be continuously updated to include new location data.

Examples of rare Balinese Hindu ritual plants are presented in Figure 3. *Sentul* (*Sandoricum koetjape*) is a tropical tree known for its round, golden-yellow fruit that has a sweet and slightly sour taste, commonly consumed fresh or processed into preserves. Fruit of *sentul* used in

rituals *loloh segara agung*. *Jali-jali* (*Coix lacryma-jobi*) is a grass-like grain plant recognized for its hard, glossy seeds, which are frequently used in traditional crafts and herbal medicine. Fruit of *jali-jali* used in rituals *ngajum sekah ngaben. Majegau* (*Dysoxylum densiflorum*) is a native Indonesian hardwood tree valued for its fragrant timber, often utilized in construction, wood carving, and ceremonial contexts in Balinese culture. Leaf and tree of *majegau* used in rituals *mantenin, murda, pengawak, prerai, pasepan, and bagia pule kerti. Biu kaikik* (*Musa ornata*), commonly known as the flowering banana or ornamental banana, is a species of banana native to Southeast Asia. It is a fast-growing, herbaceous plant admired for its striking pink to purple bracts and small, upright banana-like fruits that are typically not consumed due to their seedy texture. Leaf of *biu kaikik* used in rituals *ngaben. Rijasa* (*Elaeocarpus grandiflorus*) is a leafy tropical tree notable for its ornamental flowers and distinctive fruit, traditionally employed in local medicinal practices and believed to hold spiritual significance. Flower of *rijasa* used in rituals *nyiramang layon. Kemoning* (*Murraya paniculata*) is a small, fragrant flowering shrub widely cultivated as an ornamental hedge plant, also known for its extensive applications in traditional medicine; the flower of *kemoning* is used in rituals, *canang sari*, and *rerampen.*

**Ethnobotanical data of rare Balinese Hindu ritual plants**

Based on interviews, field observations, and literature review, 56 rare plant species used in Balinese Hindu rituals were successfully documented. One of the ritual plants, s*eminih*, has not yet been identified with a scientific name. Further studies are necessary to determine the scientific classification of these rare plant species. The ethnobotanical data of rare Balinese Hindu ritual plants are presented in Table 1.

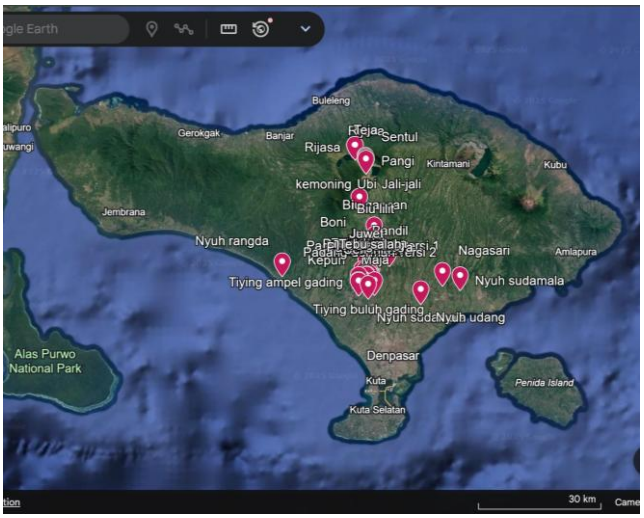


**Figure 2.** Distribution map of rare Balinese Hindu ritual plants in Bali, Indonesia (Map generated using Google My Maps and Google Earth)


**Figure 3.** Examples of rare Balinese Hindu ritual plants in Bali, Indonesia. A. *Sentul*/*Sandoricum koetjape*, B. *Jali-jali*/*Coix lacryma-jobi*, C. *Majegau*/*Dysoxylum densiflorum*, D. *Biu kaikik*/*Musa ornata*, E. *Rijasa*/*Elaeocarpus grandifloras*, F. *Kemoning*/*Murraya paniculata*

**Table 1.** Ethnobotanical data of rare Balinese Hindu ritual plants in Bali, Indonesia

| Local name | Scientific name | Family | Part used | Ritual use | Rarity | |
|---|---|---|---|---|---|---|
| | | | | | Level | References |
| *Badung* | *Garcinia dulcis* | Clusiaceae | Fruit | *Bagia pula kerti, tetukon* | Local | Pergub Bali No. 29/2020 |
| *Bandil* | *Calamus rotang* | Arecaceae | Stalk | *Ngaben dan paleletan.* | Local | Pergub Bali No. 29/2020 |
| *Bentenu* | *Melochia umbellata* | Malvaceae | Leaf | *Mantenin* | Local | Pergub Bali No. 29/2020 |
| *Bila* | *Aegle marmelos* | Rutaceae | Leaf | *Ngaben, ngodalin, bagia pula kerti, tetukon* | Local | Pergub Bali No. 29/2020 |
| *Biu gancan* | *Musa* sp. | Musaceae | Fruit | *Sawa preteka, bagia pula kerti, tetukon, raka-raka* | Local | Pergub Bali No. 29/2020 |
| *Biu kaikik* | *Musa ornata* | Musaceae | Leaf | *Ngaben* | Local | Pergub Bali No. 29/2020 |
| *Biu lalung* | *Musa* sp. | Musaceae | Tree | *Surya gede, ngaben, ngenteg linggih* | Local | Pergub Bali No. 29/2020 |
| *Biu lilit* | *Musa* sp. | Musaceae | Fruit | *Ngaben, ngenteg linggih* | Local | Pergub Bali No. 29/2020 |
| *Biu mas gading* | *Musa* sp. | Musaceae | Fruit | *Penuntun, tetukon, pangrarean, nyambleh* | Local | Pergub Bali No. 29/2020 |
| *Biu udang* | *Musa acuminata* | Musaceae | Fruit | *Raka-raka, pule kerti, tetukon, catur, nyekah, ngenteg linggih, pangrarean, nyambleh* | Local | Pergub Bali No. 29/2020 |
| *Boni* | *Antidesma bunius* | Phyllanthaceae | Leaf | *Pelas* | Local | Pergub Bali No. 29/2020 |
| *Cenana* | *Santalum album* | Santalaceae | Tree | *Pratima, prerai ngaben, dupa, melaspas, murda.* | International | IUCN Red List |
| *Cerme* | *Phyllanthus acidus* | Phyllanthaceae | Fruit | *Ngasti, suci, panca, bagia pula kerti* | Local | Pergub Bali No. 29/2020 |
| *Ceroring* | *Lansium domesticum* | Meliaceae | Fruit | *Bagia pula kerti, raka-raka* | Local | Pergub Bali No. 29/2020 |
| *Delem* | *Pogostemon cablin* | Lamiaceae | Leaf | *Paleletan, negtegan, bebayuan, ngaben, tukon, sendrong* | Local | Pergub Bali No. 29/2020 |
| *Delima* | *Punica granatum* | Lythraceae | Fruit | *Suci, nyambutin, ngaben, nyegara gunung, raka-raka, saraswati* | Local | Pergub Bali No. 29/2020 |
| *Dendeng ai* | *Cissus discolor* | Vitaceae | Leaf | *Mantenin* | Local | Pergub Bali No. 29/2020 |
| *Jali-jali* | *Coix lacryma-jobi* | Poaceae | Fruit | *Ngajum sekah ngaben* | Local | Pergub Bali No. 29/2020 |
| *Jeruju* | *Acanthus ilicifolius* | Acanthaceae | Leaf, root | *Pebayuhan melik laweyan* | Local | Pergub Bali No. 29/2020 |
| *Juwuk lengis bali* | *Citrus aurantifolia* | Rutaceae | Fruit | *Isuh-isuh melukat* | Local | Pergub Bali No. 29/2020 |
| *Kapuk* | *Ceiba petandra* | Malvaceae | Tree, fruit | *Petulangan, bagia pula kerti, tetukon* | Local | Pergub Bali No. 29/2020 |
| *Kepuh* | *Sterculia foetida* | Malvaceae | Tree, fruit | *Petulangan, bagia pula kerti, tetukon* | Local | Pergub Bali No. 29/2020 |
| *Kem* | *Flacourtia indica* | Salicaceae | Thorn | *Sayut pengelukatan* | Local | Pergub Bali No. 29/2020 |
| *Kemoning* | *Murraya paniculata* | Rutaceae | Flower | *Canang sari, rerampen* | Local | Pergub Bali No. 29/2020 |
| *Kepundung* | *Baccaurea racemosa* | Phyllanthaceae | Fruit | *Panca, loloh segara agung* | Local | Pergub Bali No. 29/2020 |
| *Maja* | *Crescentia cujete* | Bignoniaceae | Fruit | *Tetukon* | Local | Pergub Bali No. 29/2020 |
| *Majegau* | *Dysoxylum densiflorum* | Meliaceae | Leaf, tree | *Mantenin, murda, pengawak, prerai, pasepan, bagia pule kerti* | National | Permen LHK No. P.92/ MENLHK/ SETJEN/ KUM.1/8/2018 |
| *Meninjo* | *Gnetum gnemon* | Gnetaceae | Leaf, fruit | *Pelas, tetandingan banten.* | Local | Pergub Bali No. 29/2020 |
| *Nagasari* | *Mesua ferrea* | Calophyllaceae | Leaf | *Sesayut, pendeman, tebasan, pancalayuan, ngenteg linggih.* | Local | Pergub Bali No. 29/2020 |
| *Nyuh rangda* | *Cocos nucifera* | Arecaceae | Fruit | *Padudusan agung* | Local | Pergub Bali No. 29/2020 |
| *Nyuh sudamala* | *Cocos nucifera* | Arecaceae | Fruit | *Padudusan agung, caru* | Local | Pergub Bali No. 29/2020 |
| *Nyuh udang* | *Cocos nucifera* | Arecaceae | Fruit | *Padudusan agung, caru, pangrarean, nyambleh* | Local | Pergub Bali No. 29/2020 |
| *Padang derman* version 1 | *Leonurus sibiricus* | Lamiaceae | Leaf | *Pule kerti, sesayut, kuangen pengrekan.* | Local | Pergub Bali No. 29/2020 |
| *Padang derman* version 2 | *Artemisia vulgaris* | Asteraceae | Leaf | *Pule kerti, sesayut, kuangen pengrekan.* | Local | Pergub Bali No. 29/2020 |
| *Panggal buaya* | *Zanthoxylum rhetsa* | Rutaceae | Leaf | *Boreh burat wangi* | Local | Pergub Bali No. 29/2020 |
| *Pangi* | *Pangium edule* | Achariaceae | Seed | *Daksina, catur, suci, pule kerti* | Local | Pergub Bali No. 29/2020 |
| *Peji* | *Chamaedorea seifrizii* | Arecaceae | Leaf | *sanggah tutuan, surya gede.* | Local | Pergub Bali No. 29/2020 |
| *Rijasa* | *Elaeocarpus grandiflorus* | Elaeocarpaceae | Flower | *Nyiramang layon* | Local | Pergub Bali No. 29/2020 |
| *Sekapa* | *Dioscorea hispida* | Dioscoreaceae | Tuber | *Tetukon, pembersihan.* | Local | Pergub Bali No. 29/2020 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Selasih miyik* | *Ocimum tenuiflorum* | Lamiaceae | Leaf, flower | *memukur, ngajum sekah, penglukatan, isin dewa-dewi, Panjang ilang* | Local | Pergub Bali No. 29/2020 |
| *Seminih* | Unknown | Unknown | Leaf | *Mantenin* | Local | Pergub Bali No. 29/2020 |
| *Sentul* | *Sandoricum koetjape* | Meliaceae | Fruit | *Loloh segara agung* | Local | Pergub Bali No. 29/2020 |
| *Suweg* | *Amorphophallus paeoniifolius* | Araceae | Tuber | *Banten suci* | Local | Pergub Bali No. 29/2020 |
| *Tebel-tebel* | *Hoya carnosa* | Apocynaceae | Leaf | *Mantenin* | Local | Pergub Bali No. 29/2020 |
| *Tebu brahma* | *Saccharum officinarum* | Poaceae | Stalk, leaf | *Catur, nyekah, ngenteg linggih.* | Local | Pergub Bali No. 29/2020 |
| *Tebu gading* | *Saccharum officinarum* | Poaceae | Stalk, leaf | *Catur, nyekah, ngenteg linggih. pangrarean, nyambleh* | Local | Pergub Bali No. 29/2020 |
| *Tebu ireng* | *Saccharum officinarum* | Poaceae | Stalk, leaf | *Catur, nyekah, ngenteg linggih.* | Local | Pergub Bali No. 29/2020 |
| *Tebu salah* | *Saccharum officinarum* | Poaceae | Stalk, leaf | *Catur, nyekah, ngenteg linggih, mantukang dewi seri, caru* | Local | Pergub Bali No. 29/2020 |
| *Teja* | *Cinnamomum iners* | Lauraceae | Leaf | *Mantenin* | Local | Pergub Bali No. 29/2020 |
| *Teleng* | *Clitoria ternatea* | Fabaceae | Flower | *Tirta pengentas ngaben* | Local | Pergub Bali No. 29/2020 |
| *Temu gongseng* | *Curcuma heyneana* | Zingiberaceae | Rhizome | *Bagia pula kerti* | Local | Pergub Bali No. 29/2020 |
| *Tiying ampel gading* | *Bambusa vulgaris* var. *striata* | Poaceae | Stalk | *Tumpang salu, bale gading, bagia pule kerti* | Local | Pergub Bali No. 29/2020 |
| *Tiying buluh gading* | *Bambusa vulgaris* var. *striata* | Poaceae | Stalk | *Panjang ilang, klakat dewa dewi, ngangget don bingin* | Local | Pergub Bali No. 29/2020 |
| *Tunjung biru* | *Nymphaea nouchali* | Nymphaeaceae | Flower | *Sekah, panglukatan, ngenteg linggih* | Local | Pergub Bali No. 29/2020 |
| *Tuwung kokak* | *Solanum torvum* | Solanaceae | Fruit | *Biakala* | Local | Pergub Bali No. 29/2020 |
| *Ubi* | *Dioscorea alata* | Dioscoreaceae | Tuber | *Suci, penuntun* | Local | Pergub Bali No. 29/2020 |

Based on the rarity levels presented in Table 1, it can be summarized that the rarity of plants used in Balinese Hindu rituals can be classified into three levels: local, national, and international. A total of 54 species/varieties, or 96.43%, fall into the local level. Local level rarity based on exploration, direct information from traditional leaders and *Serati* who use these plants, as well as data from Bali Governor Regulation Number 29 of 2020 (Pergub Bali No. 29/2020). Only one species, or 1.79%, i.e., *D. densiflorum* is classified as protected at the national level (Permen LHK No. P.92/MENLHK/ SETJEN/KUM.1/8/2018), and one species or 1.79%, i.e., *S. album* is classified at the international level as Vulnerable (VU) by IUCN (Arunkumar et al. 2019). The comparison of the number and percentage based on the levels of rarity is shown in Figure 4.

Based on the ethnobotanical data presented in Table 1, it can be observed that there are four genera with the highest number of rare plant varieties. These genera are *Musa*, with 6 varieties (10.71%); *Saccharum*, with 4 varieties (7.14%); *Cocos*, with 3 varieties (5.36%); and *Bambusa*, with 2 varieties (3.57%) (Figure 5).

An example of the use of plants in the rituals of *Pangrarean* and *Nyambleh* is shown in Figure 6. The *Pangrarean* and *Nyambleh* ceremony in Balinese tradition refers to the ritual slaughter of animals, such as pigs, chickens, or ducks, conducted as a sacred component of Hindu religious ceremonies, including *Caru, Ngaben*, and *Odalan*. This act is not merely for consumption but serves as an offering to *Bhuta Kala* (supernatural guardians of nature) to maintain harmony between humans and the universe. The ritual is performed by a designated *Pemangku* (priest) or ceremonial leader, accompanied by specific mantras and ritual procedures. Symbolically, it represents a profound sacrifice, sincerity, and reverence toward the forces of nature and ancestral spirits, embodying the depth of meaning in Balinese culture.

**Digitization of rare plants in Balinese Hindu rituals**

All data from observations, interviews, and literature studies are incorporated into a multiplatform digital media. This digital media consists of a website and a mobile application named *Taru Yadnya*. The data included are photos, videos, locations, and ethnobotanical information of the Balinese Hindu ritual plant. The public can freely access it via the website link https://sites.google.com/view/taruyadnya/home?authuser=, or it can be downloaded through the following Google Play Store link https://play.google.com/store/apps/details?-id=com.wnapp.id1702965468863. The public can also contribute by adding new plant collections or new plant locations through the "Add Data" menu.

Website development was chosen due to its several advantages. Websites can be accessed directly through browsers on various devices without requiring downloads or installations, making them more convenient for users. A larger screen display allows for a clearer and more readable presentation of information, maximizing the use of visuals such as images and videos. In terms of cost, the development and maintenance of websites are generally less expensive.

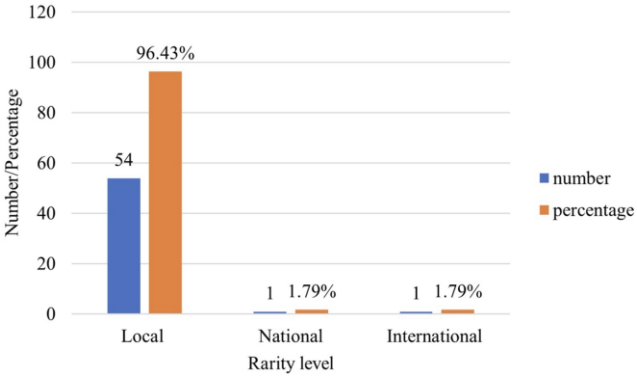


**Figure 4.** The number and percentage of Balinese Hindu ritual plants based on rarity levels in Bali, Indonesia

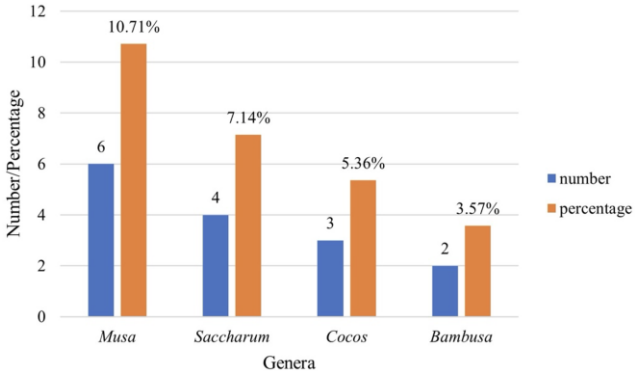


**Figure 5.** Number and percentage of the rarest Balinese Hindu ritual plant genera in Bali, Indonesia


**Figure 6.** Example of the use of plants in the *Pangrarean* and *Nyambleh* ritual. A. *Biu/Musa*, B. *Nyuh/Cocos*, C. *Tebu/Saccharum*

Additionally, websites can be updated in real-time without requiring users to install updates manually. The websites are also highly searchable and can be optimized for search engines (SEO), enabling broader organic reach (Chauhan et al. 2023). On the other hand, the development of mobile applications aims to provide users with convenient, responsive, and personalized access to *Taru Yadnya* information, particularly in mobile and on-the-go contexts (Khrais and Alghamdi 2021). Thus, the local wisdom of Balinese Hindu ritual ethnobotany has been stored in an internet-based digital database, accessible freely by anyone, at any time, and from anywhere. The appearance of the *Taru Yadnya* media on various platforms is shown in Figure 7.

**Design of transdisciplinary biology learning media based on local wisdom**

The *Taru Yadnya* website and mobile application are also designed as media for transdisciplinary biology learning through a student project menu. This design is displayed in Figure 8. The *Taru Yadnya* media facilitates learners in studying biology through project-based learning. They not only learn from educators but can also collaborate with the community, government, and industry stakeholders. Learners can collaborate with the government to design cultural heritage projects, nature reserves, and conservation policies. Learners can work with industry actors to design eco-tourism and ethno-market projects. They can also collaborate with the community to design tutorials on the use of *Taru Yadnya*, customary laws, and craft products. Thus, the goal is for biology learning to become a more meaningful and beneficial transdisciplinary learning experience.

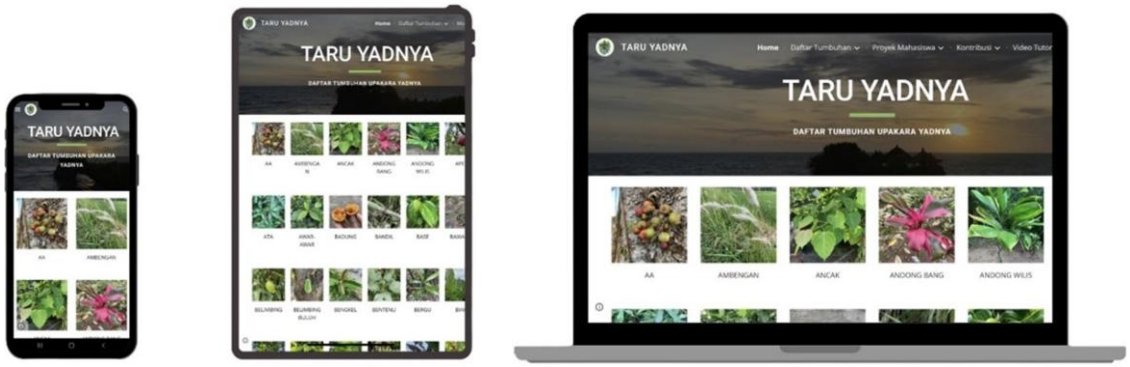


**Figure 7.** *Taru Yadnya* media display on various digital platforms. A. Smartphone, B. Computer tablet, C. Laptop

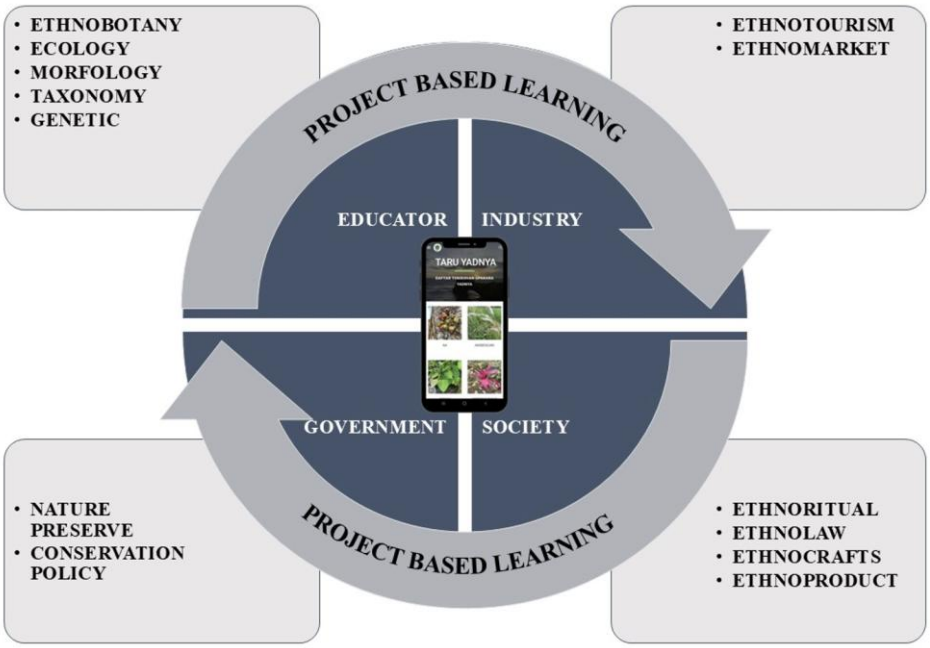


**Figure 8.** The design of *Taru Yadnya* integration as a transdisciplinary biology learning media

**Discussion**

Based on the research findings, the rarity of plants in Balinese Hindu rituals can be classified into three levels: local, national, and international. Local rarity occurs at the variety level, such as the varieties of *Biu* (*Musa*), *Tebu* (*Saccharum*), and *Nyuh* (*Cocos*). National rarity includes plants like *Majegau* (*D. densiflorum*). International rarity includes plants like *Cenana* (*S. album*), which is listed as a rare plant on the IUCN Red List of Threatened Species (Arunkumar et al. 2019; Gurusamy et al. 2024). Variety-level rarity is the result of genetic expression due to mutations or crossbreeding between plants (Kandoliya et al. 2018; Martínez et al. 2024). This genetic variation is one of the factors that makes plants rare. In addition to genetic factors, the rarity of plants is also caused by human activity. For example, the rarity of *Majegau* plants is due to excessive exploitation and the lack of conservation efforts.

Research findings can serve as a reference for plant conservation programs by communities, governments, business actors, industries, educational institutions, and other stakeholders; first, the government. Research findings can provide the basis for both in situ and ex situ plant conservation programs. Distribution data can offer guidance for habitat monitoring and protection programs (Handayani 2018; Xu and Zang 2023; Bachman et al. 2024). Distribution data can also inform programs for plant propagation through both generative and vegetative methods. Plant species data can indicate priority species that need to be conserved. Varieties of coconut, banana, and sugarcane are the most frequently used ritual plants (Miyaura et al. 2015; Hidayat et al. 2018; Rai et al. 2018; Sujarwo et al. 2020). However, some of these varieties are increasingly difficult to find. Therefore, they should be prioritized in conservation programs. In situ conservation can be conducted through the development of nature reserves or cultural heritage sites. Ex situ conservation can be carried out through the establishment of ethno-gardens. Ex situ conservation could collaborate with the Eka Karya Bali Botanical Garden.

Second, business actors and industry stakeholders. Research findings provide opportunities to offer services in the supply of rare ritual plants. They can act as both producers and distributors. Another opportunity is the development of ethno-tourism focused on rare ritual plants. Culture-based creative economies are highly profitable in today's modern era (Ericsson et al. 2024; Shafiee et al. 2025). Thus, indirectly, these activities contribute to the availability and conservation of plants.

Third, educational institutions can utilize *Taru Yadnya* as a learning medium based on local wisdom. Audiovisual learning media have a positive impact on student learning outcomes (Ibe and Abamuche 2019). Audiovisual learning media can enhance memory, interest, and learning motivation among students (Groß et al. 2022; Uda et al. 2024). On the other hand, learning media based on local wisdom can foster students' love for their culture, teach character values, and make learning more meaningful (Gani et al. 2024). *Taru Yadnya* is also designed to apply project-based learning. Project-based learning has several advantages, such as training critical thinking skills, problem-solving skills, and collaboration skills, and providing real-world learning experiences that are more engaging and meaningful (Larmer et al. 2015; Wurdinger 2016; Hujjatusnaini et al. 2022; Sukaesih et al. 2022; Buroidah et al. 2024; Chamidah et al. 2024).

The limitations of this study can be described as follows: (i) The research was conducted within a limited timeframe of only six months, resulting in incomplete data, such as videos documenting the preparation and utilization of ritual plants; (ii) The digitalization into augmented reality and virtual reality formats has not yet been carried out, which could enhance the *Taru Yadnya* digital media; (iii) The effectiveness of the *Taru Yadnya* learning media has not yet been tested. Therefore, these limitations will serve as the focus of future research.

Based on the results and previous discussion, it can be concluded that 56 Balinese Hindu ritual plants are classified as rare species. These plants have been digitized into a website and mobile application called *Taru Yadnya*. *Taru Yadnya* has also been designed as a transdisciplinary biology learning medium based on local wisdom. The research findings can serve as a reference for plant conservation programs. The focus of future research will be to develop an ethno-ritual garden and to evaluate the effectiveness of *Taru Yadnya* in biology education.

## ACKNOWLEDGEMENTS

This research was funded by the Indonesian Center for Higher Education Funding and Assessment (PPAPT), Ministry of Higher Education, Science, and Technology of the Republic of Indonesia; the Indonesia Endowment Fund for Education (LPDP), Ministry of Finance of the Republic of Indonesia; and the Indonesian education scholarship (BPI). We would like to thank them for their financial assistance.

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