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RESEARCH ARTICLE

Design and Implementation of a Digital Herbarium Database: The Case of the Bilgehan Bilgili Herbarium

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ABSTRACT

Herbaria are essential repositories for documenting plant biodiversity and provide irreplaceable data for taxonomic, ecological, and conservation-oriented research. However, the rapid growth of herbarium collections has increasingly challenged the efficient management, accessibility, and long-term sustainability of specimen data. In this study, the design and implementation of a digital herbarium database are presented through a case study of the Bilgehan Bilgili Herbarium at Kastamonu University (Türkiye). Approximately 2,000 vascular plant specimens, primarily collected from northern Türkiye, were revised, standardised, and digitised in accordance with international herbarium and data management standards. Specimens were identified using up-to-date taxonomic sources, relabeled where necessary, imaged using high-resolution digital photography, and integrated into a relational database developed with Microsoft SQL Server. A web-based virtual herbarium interface was subsequently created using ASP.NET technology to enable remote access to specimen data and images. As a result, 1,563 taxa belonging to 107 families, including 134 endemic taxa, were recorded and made digitally accessible. The most represented families were Asteraceae, Fabaceae, and Lamiaceae, while Euro-Siberian phytogeographical elements predominated. The developed digital infrastructure significantly enhances data accessibility, reduces risks associated with physical specimen handling, and supports regional floristic research, biodiversity analyses, and conservation planning. This study demonstrates that the digitisation of herbarium collections provides a sustainable and scalable model for improving the management and global accessibility of botanical data, and it offers a practical framework for similar initiatives in Türkiye and beyond.

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1. Introduction

Plants are fundamental components of biological diversity and constitute indispensable research material for numerous disciplines, including ecology, medicine, forestry, agriculture, pharmacy, and environmental sciences. In this context, plant specimens are collected for scientific purposes, dried, and preserved in herbaria for long-term storage (Borsch et al., 2020). Herbaria represent collections of critical importance at the global scale for documenting, monitoring, and conserving plant diversity. With the increasing scope of biological and ecological research, both the number of herbaria and the volume of their collections continue to grow steadily.

Beyond their role in species identification, nomenclature, and classification, herbaria provide valuable information on historical vegetation patterns, past climatic conditions, species distributions, and traditional uses of plants. They also serve as primary data sources for developing conservation strategies for threatened plant species. In this regard, herbaria play an indispensable role in advancing plant science and biodiversity conservation.

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In parallel with scientific and technological advances, the scope of herbarium use has expanded considerably. Initially established primarily for the identification and classification of plants, herbaria are now widely used in diverse research fields, ranging from medicinal plant studies to the monitoring of climate change and phenological shifts, from assessing historical plant responses to atmospheric carbon dioxide fluctuations to tracing isotopic signatures of environmental change, and from investigating the spread of plant pathogens to the detection of invasive species. Indeed, herbaria have been shown to support more than 72 distinct scientific and applied uses (Harris & Marsico, 2017; Cantrill, 2018; Funk, 2018; Sass-Gyarmati & Táborská, 2020). According to Index Herbariorum data, as of 2025, a total of 406,426,591 specimens are preserved in 4,035 active herbaria worldwide. In Türkiye, 1,168,727 specimens including native flora and numerous foreign plant samples are housed in 72 herbaria (URL-1). These figures highlight the strategic importance of herbaria for documenting and conserving Türkiye's floristic richness.

As herbarium collections expand, the management of locality, morphological, phenological, and ecological data associated with plant specimens becomes increasingly complex. Accessing such information through physical collections alone has become time-consuming and restrictive, particularly as specimen numbers grow. Consequently, various database management systems have been developed to enable more efficient, reliable, and sustainable management of herbarium data (Akman et al., 1996; Geven et al., 2008). Advances in information technologies have rendered the digitisation of herbarium collections inevitable (Vaganov et al., 2021).

In recent years, virtual herbaria have rapidly proliferated due to developments in computer technologies, high-resolution digital imaging systems, GPS-based geolocation tools, and internet infrastructure. Digital herbaria are systems in which images of plant specimens, label information, and locality records can be stored in detail, queried, and accessed remotely. These systems not only facilitate collection management but also enhance data sharing among researchers, thereby strengthening scientific collaboration (Nelson et al., 2012; Soltis, 2017; Paton et al., 2025).

In traditional herbaria, researchers typically accessed specimens either through postal loans or on-site visits. However, these methods involve several challenges, including the risk of specimen damage, loss during shipment, and temporal constraints. Digitisation of herbarium data substantially reduces these risks while simultaneously enabling access for a much broader user community. Digital collections also allow large-scale analyses, particularly in fields such as climate change research, biogeography, and conservation biology (Bebber et al., 2010; Page et al., 2015).

In Türkiye, efforts to improve the management of plant data have accelerated over the past two decades, particularly through the establishment of digital plant databases. Physical collections that were previously accessible to a limited number of researchers are now being transformed into comprehensive data resources that support multidisciplinary research through digitisation initiatives. In parallel with these developments, virtual herbarium projects have also emerged, aiming to provide online access to high-resolution specimen images and associated metadata. Early examples of such initiatives in Türkiye include the study by Öztürk and Ege (2014), which highlighted the importance of digitising herbarium materials and establishing web-based access systems. More recently, Çiftçi et al. (2023) and Aslan et al. (2024) presented applied models and case studies focusing on the development, management, and research potential of virtual herbarium infrastructures in the country. These studies demonstrate that virtual herbaria not only enhance accessibility but also contribute to biodiversity monitoring, conservation planning, and interdisciplinary scientific collaboration. Nevertheless, digitisation efforts remain limited in many Turkish herbaria, highlighting the need for new projects in this field.

Within this framework, the present study aims to organise, revise, and update the label information of approximately 2,000 plant specimens primarily collected from the surrounding region housed in the Bilgehan Bilgili Herbarium of the Faculty of Forestry at Kastamonu University. In addition, the study seeks to establish a virtual herbarium infrastructure by transferring all specimen data into a digital environment. This initiative is intended to provide faster and more reliable access to plant data for researchers at the university and for all scientists working on the flora of northern Türkiye.

In conclusion, digitising herbaria in Türkiye will not only enable the effective management of data related to the country's rich plant biodiversity but also strengthen scientific collaboration at national and international levels. The virtualisation of the Bilgehan Bilgili Herbarium represents an important step toward ensuring the sustainability of regional floristic research.

2. Materials and Methods

2.1. Study Area and Plant Material

The material of this study consists of plant specimens collected by academic staff and students of the Faculty of Forestry at Kastamonu University as part of various regional flora and vegetation studies. The research was conducted within the Bilgehan Bilgili Herbarium of the Faculty of Forestry, which is currently in its establishment and development phase. The herbarium collection comprises approximately 2,000 vascular plant specimens collected primarily from Kastamonu and its surroundings, as well as from other parts of northern Türkiye.

Collected specimens were pressed, dried, and mounted on herbarium sheets in accordance with standard herbarium techniques (Smith & Chinnappa, 2015). Species identifications were carried out using relevant floristic sources and up-to-date taxonomic literature, and the current validity of species names was verified using international plant databases (e.g. POWO, IPNI).

2.2. Labelling and Collection Arrangement

Standard label information was prepared for each herbarium specimen, including family, genus, species, subspecies, variety, grid system, province, district, locality, habitat, altitude, collector name, collection date, and identifier name. Labels were prepared in accordance with herbarium standards and affixed to the specimen sheets.

Following labelling, specimens were arranged alphabetically by family and placed on herbarium shelves. This organisation aimed to improve physical accessibility and ensure data integrity during the digitisation process.

2.3. Digital Imaging Process

Specimens whose identification and labelling were completed were subjected to the digitisation process. Each herbarium sheet was photographed in a manner that ensured clear visibility of label information (Figure 1). High-resolution digital cameras were used to preserve morphological details of the specimens.

Figure 1. Prepared herbarium specimens.

The resulting digital images were processed using Adobe Photoshop software, with adjustments made to colour balance, sharpness, and readability. This stage is consistent with image enhancement practices commonly employed in international virtual herbarium projects.

2.4. Database Development and Management

All label data and images associated with the digitised specimens were transferred to a dedicated database. Taxa were listed to create a comprehensive inventory of the herbarium collection. The database infrastructure was developed using Microsoft SQL Server, which was also employed for data management.

The database was structured to support taxonomic queries, locality-based filtering, altitude and habitat analyses, as well as user authorisation, data updating, and backup procedures. This architecture complies with international standards recommended for the digital management of biological collections (Page et al., 2015).

2.5. Development of the Web-Based Virtual Herbarium

To provide online access to the database, an ASP.NET-based web interface was developed on the Microsoft SQL Server infrastructure. Adobe Dreamweaver software was used in the design of the web pages. The virtual herbarium system

was integrated into the internet infrastructure of Kastamonu University and made accessible at: http://herbaryum.kastamonu.edu.tr (Figure 2).

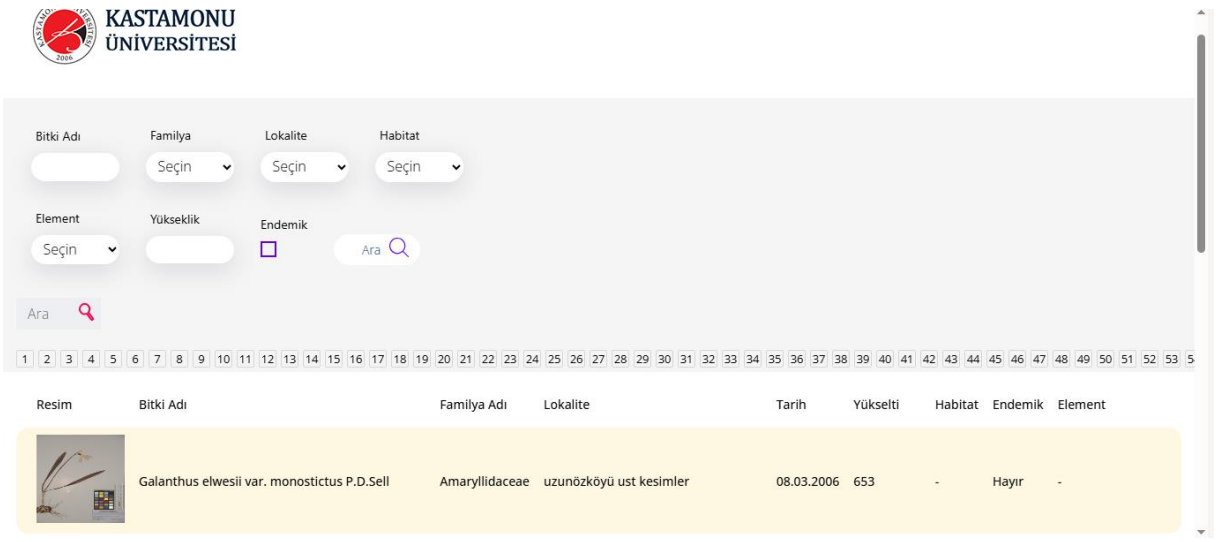

Figure 2. View of the virtual herbarium website.

The developed virtual herbarium enables researchers to remotely access plant specimens, conduct taxon-based searches, and view high-resolution images of specimens. This approach aligns with global digital biological collection initiatives aimed at increasing the accessibility of herbarium collections worldwide (Bebber et al., 2010; Nelson et al., 2012; Markiewicz et al., 2025).

3. Results and Discussion

Within the scope of this study, the plant collections of the Bilgehan Bilgili Herbarium at the Faculty of Forestry, Kastamonu University, were organised, revised, and recorded in accordance with herbarium standards. Throughout the organisation process, avoiding damage to specimens was adopted as a fundamental principle. Specimens previously incorporated into the herbarium but lacking complete or up-to-date label information were re-labelled accurately. Mounted specimens were arranged alphabetically by family and placed in cabinets, resulting in a systematic structure both physically and digitally.

A total of 1,563 taxa belonging to 107 families were entered into the database of the Bilgehan Bilgili Herbarium. Of these taxa, 134 are endemic. This result demonstrates the herbarium's considerable potential for documenting regional floristic diversity. With future flora and vegetation studies conducted at the university, the number of taxa in the collection is expected to increase.

An examination of families with the highest number of specimens revealed that Asteraceae ranked first with 169 specimens, followed by Fabaceae (149) and Lamiaceae (127). This pattern likely reflects the wide distribution of these families in the flora of Türkiye and their adaptability to diverse habitats. At the genus level, the most represented genera in the collection were *Trifolium* (29 specimens), *Salvia* (22), and *Astragalus* (21). The high representation of *Astragalus* and *Salvia* is consistent with Anatolia being a major centre of diversification for these genera. This finding indicates that the herbarium may serve as an important reference source for taxonomic and phytogeographical studies.

Analysis of the phytogeographical distribution of plant taxa revealed a predominance of Euro-Siberian elements. This pattern is directly related to the geographical location and climatic characteristics of Kastamonu and its surroundings. Although the region exhibits transitional zone features, the data indicate a strong influence of the Euro-Siberian floristic region.

Through this study, all specimens were formalised as herbarium material, a current and standardised plant list was created, and all associated data were transferred to a digital environment. The resulting database provides rapid and reliable access to specimens, label information, and images, reducing the need for physical visits and offering significant advantages in terms of time and cost for scientific research.

In Türkiye, several virtual herbarium initiatives now provide publicly accessible specimen data and images, enabling comparative analyses with new research findings. For example, the Nezahat Gökyiğit Botanik Bahçesi Virtual Herbarium has transferred the data and images of its approximately 16,000 plant specimens online as part of its digitisation efforts, making them easily accessible through a web portal for researchers and the public (URL-2). Similarly, the IZEF Virtual Herbarium at Ege University has digitised and published around 6,000

herbarium specimens in its TürkiyeFlorası 1.0 database, representing the first large-scale virtual herbarium project in the country (URL-3). Another notable example is the Van Gölü Havzası (VHLV) Virtual Herbarium, where approximately 9,000 identified plant images and records have been made available online, contributing to regional biodiversity documentation and research (URL-4). More comprehensive digitisation models, such as the DUOF Virtual Herbarium at Düzce University, have also scanned and incorporated roughly 11,000 herbarium specimens into their searchable digital systems, highlighting the growing emphasis on digital infrastructure in Turkish herbaria (URL-5). These examples illustrate the expanding landscape of virtual herbaria in Türkiye and demonstrate their value as comparative data sources for contemporary floristic and biodiversity studies.

The database software developed for transforming the Bilgehan Bilgili Herbarium into a virtual herbarium was designed to accommodate the integration of new data and future updates, allowing the herbarium to evolve into a sustainable digital biological collection over the long term.

Digitisation of the herbarium collection has minimised risks associated with specimen loans and postal shipment of physical materials. Moreover, the digital data infrastructure has transformed the collection into a sustainable data source for floristic research, biodiversity analyses, and conservation biology studies (Soltis, 2017).

In conclusion, this study makes a significant contribution to the preservation of regional floristic knowledge and the support of scientific research by organising, documenting, and digitising the Bilgehan Bilgili Herbarium. Serving as a model for the digitisation of herbaria in Türkiye, this work offers an applicable framework for similar collections.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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