Plant Archives Vol. 25, Supplement 1, 2025 pp.495-509 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-1.067

LEAF BASED PLANT IDENTIFICATION USING TRADITIONAL AND AUTOMATED METHODS: A REVIEW

Vidya Arora[1], D.S. Rawat[1], Nidhan Singh[2], Shri Prakash Dwivedi[3] and Preeti Chaturvedi[1]*
[1]Department of Biological Sciences, College of Basic Sciences & Humanities, G.B. Pant University of Agriculture & Technology, Pantnagar-263145, Uttarakhand (India).
[2]Department of Botany, IB (PG) College, Kurukshetra University, Panipat-136119 Haryana (India).
[3]Department of Information Technology, College of Technology, G.B. Pant University of Agriculture & Technology, Pantnagar-263145, Uttarakhand (India).
*Corresponding Author Email: an_priti@yahoo.co.in
(Date of Receiving : 24-07-2024; Date of Acceptance : 30-09-2024)

ABSTRACT

Identification of plants is necessary before diving into their ecological and economic significance. Plant experts and botanists typically rely on traditional methods to identify plants, focusing on collecting, preserving, and studying distinctive characteristics of different plant parts. Plant identification by their leaves is easier than by their fruits or flowers because leaves are visible throughout the year. In addition to these conventional methods, contemporary approaches have emerged, enabling even computer engineers and nature enthusiasts to identify plants effectively. These modern methods utilize various types of computer-based plant identification applications and different types of neural networks for image-based identification. In this review, the comparison of conventional and automated techniques provides all the information needed for the identification of the plants. This study will surely benefit students, academicians and lovers of nature by expanding their understanding of the identification of plants in the light of various conventional as well as computational tools available today.
Keywords **:** Leaf, Floras, Taxonomic Keys, Neural Network, Mobile Apps, Image Processing.

Introduction

The leaf is an immensely important arboreal organ of the plants that produces food and liberates oxygen by absorbing sunlight and carbon dioxide from the atmosphere. Structurally, a leaf consists of a broad expanded part attached to the plant stem or branch by petiole. The flattened part of the leaf is called as leaf blade or lamina which can be subdivided into three discrete regions i.e., apex, base and margin (Singh, 2010). The two types of leaves i.e., simple and compound leaves is one of the most basic features used for plant identification. Besides, phyllotaxy on the plant body such as alternate or spiral, opposite and whorled (Hussain *et al.*, 2021) is very useful feature of identification (Fig. 1).

Identification of an organism is a must-do act before taking steps for its utilization. Identification is a process of recognizing an unknown sample with an already present specimen in herbarium or known taxon in E-floras. It involves both classification and nomenclature. In identification, first a plant is described with complete morphological characteristics of vegetative and reproductive parts. More criteria of identification include a list of possibilities like referring to regional floras, taxonomic keys and specimen and /or image comparison etc. (Simpson, 2010).

The plants as trees, shrubs are identified by studying the vegetative features like leaves and bark and/or reproductive features like flowers (cones) and fruits. Generally, plants are seasonal bearers of flowers and fruits. Moreover, they have a short flowering season and many a times, flowering isn't always predictable. Besides, shape, size, colour of fruits and flowers are also changing during growth. Compared to reproductive characters, bark is an important feature of tree species which is relatively stable character and hence greatly used for identification (Fiel and Sablatnig, 2010). Bark has great taxonomic value because it is observable throughout the year unlike flowers/ leaves, in deciduous trees. Smooth, scaly, plate like, stripped, peeling ridged and furrowed are the six major bark types (Wojtech, 2011). Bark is recognized by the appearance of surface pattern. However, sometimes it is difficult to correctly identify a tree solely based on the basis of bark character, as bark appearance changes with age, as age and bark characteristics are correlated. Bark on upper trunk is sometimes younger and different in appearance than that on the lower trunk. Hence, for identification of trees based on bark, only mature trees are relied upon (Wojtech, 2011). Till a tree reaches an age of maturity, bark- based identification sometimes is not very trustworthy.

To overcome this issue, in addition to bark and floral features, many researches use leaf characteristics in tree identification. Barring the dormant season in deciduous trees, leaves are a constant feature of a tree. Unlike bark, leaf structure generally does not change with age except its size and colour. Leaves thus form comparatively easily available and reliable taxonomic character that can be used for identification of trees. Many macro-morphological characteristics of leaves are available for observation and comparison of different tree species in forests (Hardin *et al.,* 1929). Studies have used leaf features like shape (apex, base), texture information, and venation to identify plants (Hassoon *et al.,* 2011). However, studying the morphological traits of leaves and contrasting them with those of related families and specimens necessitates a large amount of effort in order to identify tree species based on their leaves. Identification of different varieties of mango tree is also done by studying leaf features like leaf length, width, petiole length, leaf apical process, base shape and posture (Arora *et al.,* 2024). Two types of methods are usually employed for identification of plant species i.e., traditional methods and automated methods. Identification by traditional methods involve “creation of taxonomic keys, written description, specimen comparison (herbarium specimen), image comparison, expert determination and practical identification” (Simpson, 2010). Traditional method is a very long process involving visit to different areas, collection of leaf samples, taking photographs of leaf samples, preservation and maintenance of samples, and study of available resources like floras and books etc. In automated methods, the identification is done by using different devices like digital cameras, mobile apps, computer vision and image processing including different types of neural networks like “support vector machine (SVM), artificial neural network (ANN), convolutional neural networks (CNN) and k-nearest neighbour (KNN) classifier, probabilistic neural network (PNN)”(Azlah, 2019). This manuscript discusses the available conventional methods, automated identification methods and different computational strategies for leaf-based identification of plants.

The conventional method of plant identification is a long process. Fig. 2 shows different steps of identification of plant species.

Collection of sample

Sample collection is ideally done from various locations. For simple leaf, the supporting branch needs to be cut in such a way so that the attached petiole, axillary buds and stipules are retained. In compound leaf, care should be taken to collect intact leaves in such a manner so that petiole attachment to the stem and branches pattern is also retained (Bridson and Forman, 1998). Usually, a terminal twig with 3-4 mature leaves should be collected. However, gigantic size of many tall trees makes it difficult for researchers to collect plant leaves. So, the leaves are collected which fall due to wind or dropped by squirrels, monkeys and other animals (Ingalhalikar, 2020). “Arborist throw-line launcher” is a tool used for collection of leaf or seed sample from very tall trees (Youngentob *et al.,* 2016). The other way to collect leaf or seed sample from tall tree is to use a pruner which can be attached to a bamboo stick. This instrument helps to collect sample from tree species. The tree leaves which are collected from different areas are preserved with the proper note in which date and time of collection are mentioned along with the location for further studies.

Graphical images and photographs

During the collection of leaf samples, photographs of the live tree species and their leaves are taken with the help of camera in the field to show the shape, size, colour and morphology of the leaf. After taking leaves' photographs, a full-size leaf sample should be cut and put onto the board which is covered by graph paper. Then a photograph is taken to know the phyllotaxy, measure the actual size of the leaf, petiole and other details of leaf morphology (Fig. 3).

Preservation and maintenance of collected samples

Collected specimens are then pressed under field press in between the sheets of newspapers to make them dry following the method suggested by Bridson and Forman. Plants pressed in the field will yield specimens of higher quality than those wrapped, bagged and pressed later. After final drying by repeated newspaper changes, pressed leaf material is poisoned with mercuric chloride ($HgCl_2$) solution made in ethyl alcohol (1 gm $HgCl_2$ in 100ml ethyl alcohol) to prevent the attack of pests, fungi etc. To prevent the attack of insects in the herbarium, powdered naphthalene balls is also used as a repellent. Once completely dry, the specimens are mounted on the standard herbarium sheets (42×28 cm) and labelled by a label of 8×12 cm (Jones and Luchsinger, 1986).

Conventional methods of identification

Trees are identified by analysis of many characteristics such as bark, leaves, flowers and fruits or cones. For identification purpose, one should have these skills: (1) knowledge in plant taxonomy, its methods and terms; (2) experience in herbarium lab; (3) experience in the identification of plants (Jones and Luchsinger, 1986). Professionals usually identify their specimens after they have been pressed and dried. Plants are generally identified by comparing them with the named plant specimens.

Identification by taxonomic keys

Identification of specimen by the use of taxonomic keys is an efficient method than to shuffle through a stack of previously named herbarium specimens. A taxonomic key is an identification device which is used to narrow down the series of contrasting statements. A dichotomous key consists of two contrasting choices. Each choice is known as lead and two leads are called couplet. During identification process, one lead of a couplet is acceptable for a given taxon and the other lead is applicable to other taxa, as the key progresses. The indented or yoked key and bracketed key is widely used in manual for identification of vascular plants (Jones and Luchsinger, 1986). Another method for identification is polyclave key. It consists several choices and select all choices that match to the specimen (Simpson, 2010).

Identification by written description

Written description is another way to identify a plant species. Written description makes a clear picture of plant in our mind. The written characteristics makes the identification process easier and precise taking into account a good list of available characteristics. For this, regional floras and books are very helpful for identification.

1. Identification using books

For identification of tree species using leaves, many a times books are quite useful. Kishen (2006), studied 262 species of trees in his book, Trees of Delhi, and identified trees based on 10 categories of leaves, 5 from simple leaves and 5 from compound leaves (Krishen, 2006). All of these leaf categories are used to identify approximately 262 tree species. In the book, Jungle Trees of Central India, author Krishen used the shape of leaf as the primary clue to identify all trees listed in that work (Krishen, 2013). He classified leaves as simple or compound. Simple leaves can further be untoothed, toothed, or lobed. The compound leaves were divided into three types: digitate, pinnate, and twice pinnate. Approximately 172 trees were identified based on these six leaf categories. Leaf-based identification for trees of Sahyadri, by Ingalhalikar, explains all taxonomic characters of leaves from 434 species of forest, mangrove, and urban trees in India's North Western Ghats (Ingalhalikar, 2020). He classified trees based on the leaf types into simple and compound leaves and identified trees from leaf characters based on innovatively generated keys. Besides the variation in leaf shape, size or colour, characters such as leaf type, attachment, nerves, glands, odour, spines and latex were constant in most families and species. These characters were used to distinguish species in identification keys.

2. Identification using floras

Floras are very much used for identification of plant species. For example, number of floras are available focussing on forest vegetation of Uttarakhand. "Duthie's Flora of the Upper Gangetic Plain and Adjacent Siwalik and Sub-Himalayan Tract", Vol 1 describes 175 trees indigenous to the Tarai region (Duthei, 2017). "A Forest Flora for Kumaon" by Osmaston, describes 816 species of arborescent plants, including 290 trees (Osmaston, 1927). Gaur (1999) listed 2,150 species from 1032 genera and 189 families in "Flora of the District Garhwal, North West Himalaya: With Ethnobotanical Notes". Gupta (1968) reported 457 genera over 125 families and 869 species containing 95 tree species from the Nainital district in "Flora Nainitalensis: A Handbook of Flowering Plants of Nainital". "Flora of Uttarakhand", Vol. 1, by Pusalkar and Srivastava, describes 873 taxa, 827 species from 274 genera in 65 Gymnosperm and Angiosperm families (Ranunculaceae to Moringaceae) (Pusalkar and Srivastava, 2018). Plant description given in these floras can be used for identification purpose. Besides, these regional floras, many other floras available for the state, country and nearby regions can also be consulted.

Identification using image comparison

Image comparison is an excellent and comparatively faster way to identify an unknown taxon. By using images given in books, eBooks, eFloras and webpages. One may identify unknown tree species by using their photographs and illustrations. However, this method is only applicable for small number of possible taxa and there may exist two or more taxa which looks very similar to one another (Simpson, 2010).

Identification using specimen comparison

In this method, identification of tree species is done by comparing the unknown sample with a live sample or preserved herbarium specimen. Here, so many features are available for observation which cannot be seen in written description and image comparison (Simpson, 2010).

Expert determination method

By asking someone else, preferably an expert of local flora is a simple means of identification of plant species (Szejner, 2017). Expert determination is very important when we work on some groups in which species and infraspecific identification is very difficult (Simpson, 2010).

Automated identification

Extinction of species in nature is one of the most serious problems faced by planet earth. Any attempt to conserve a threatened species essentially requires correct identification of that species. It is possible only through long training and experience in plant identification. Herein, the role of modern automated tools becomes highly significant. The automated tools make use of relevant computational technologies and gain remote access to databases which is further used in image processing and pattern recognition. Based on this image-based data, identification of a species is done. Researchers, farmers, interested nature lovers greatly benefit from the automated tools.

Concept of leaf recognition in automated methods

Plant recognition goals typically revolve around elements such as the features of leaves, flowers, branches and trunks. Among these parts, the leaf is often considered the most convenient for recognition. Recognition of leaves primarily focuses on the broad leaves (Rzanny *et al.,* 2017). Number of different leaf features such as leaf shape, colour, vein, texture etc. are used together for leaf description using various techniques.

Applications for identification of plant species using leaf images

Identification of plant species using digital images of leaves is now possible. Various types of applications (apps) are available on mobile phones for plant identification. These apps include 'Leaf Snap', 'Plant Snap', 'Pl@ntNet', 'Google Lens', 'iNaturalist' and 'Seek', all of which are free to use. The 'PictureThis' app shows 99% accuracy, but is not yet usable in India and requires payment. These apps essentially require the photograph of available plant parts. Upon uploading these images, the scientific name of the plant appears below the image. Observations can be saved and the next plant can be identified in the same manner. The identification of the next plant will automatically save the images of the previous plant. Other apps such as 'Plantifier', 'Flora incognita' and 'Plantlens' are also used for plant identification. The apps, '*Verginia incognita'* and '*iTrees'* provide details of many trees and are quite helpful for tree identification. Details of these identification applications including their uses and drawbacks are given in Table 1.

A comparative account of the accuracy of all these identification apps following Wootton, (2021) is provided in Fig. 1. According to this analysis, 'iNaturalist' and 'Leaf Snap' apps demonstrate high accuracy rates (≥90%); 'Google Lens' shows less accuracy comparatively. However, according to Hill (2022), among all the available apps, the 'Picture This' app, shows the highest accuracy followed by 'Pl@ntNet', 'Leaf Snap' and 'iNaturalist'.

Identification by computational techniques

Neural networks are the study of computational elements i.e., neurons which are interconnected with each other. They include the input layer, hidden layer and outer layer (Sumathi and Kumar, 2014). Automated identification methods are based upon use of different types of neural networks for plant identification. Computer based identification techniques typically involve four steps i.e., acquisition, preprocessing, feature extraction and classification (Hasna and Jithendra, 2020; Fig. 4). During the acquisition phase, a few datasets containing 8–10 leaf images of a plant species are collected. The leaf images are captured against a white or neutral background or in their natural environment. Subsequently, these leaf images are processed. Image processing involves analysing digital images for improving their quality and has extensive application in pattern recognition and machine learning etc. (Prathan and Nayak, 2021). In the image preprocessing procedure, various programming languages, such as Java, Python, MATLAB, and OpenCV are used. Python, a freely available language, can be easily downloaded from the internet. Python also offers multiple libraries for various purposes, including the Python image processing library (PIL) which is dedicated to image processing and freely available for download (Gujar *et al.,* 2016). In this procedure, the leaf image is first converted to gray-scale. This gray-scale image is further converted to a binary image, which is then used for studying its internal features. Following this, machine learning process begins, during which the features of the leaf are extracted. Visual features of the leaf can be categorized as general and domain related visual features. General features include leaf shape, colour, texture which are not directly related to the content of the images. For leaf recognition, domain related features such as dent, vein and shape are extracted (Wu *et al.,* 2015). Subsequently, these features are used for classification. Various types of classifiers are employed in this process, such as Support Vector Machines (SVM), k-Nearest Neighbors (KNN), Convolutional Neural Networks (CNN), Artificial Neural Networks (ANN), Probabilistic Neural Networks (PNN), and others. One of the simplest classification techniques in machine learning is Nearest-neighbour classification. The nearest-neighbour classification comprises training, validation and testing phases. Depending on the requirement, overall dataset is divided into training, validation and test datasets and sometime only training and test datasets are used. Initially, the classifier is trained using the training datasets. If necessary, different parameters are validated using the validation datasets. Once, the quality of the available training data is assessed to be clear and satisfactory, the accuracy of automated plant identification is determined properly (Rzanny *et al.,* 2017). Subsequently, the testing dataset is used to evaluate the actual accuracy of the classifier. These steps for computer-based identification process are given in the flowchart (Fig. 5).

Feature extraction

The camera of mobile or a good camera captures the leaf image. Next, the signals of camera are pre-processed without losing important information. Segmentation operation is then used to isolate the images of different leaves from one another and from the background. Subsequently, the information from a single leaf is sent to a feature extractor which reduces the data by measuring certain features. These features are then passed to a classifier which determines the species based on their leaves (Duda *et al.,* 2006).

Leaf characters used for automated identification

Leaf shape, colour and leaf angle

Leaf shape provides valuable information for plant identification. Leaf venation, colour, texture and margin are the other important characters used for leaf-based identification and classification. Among these leaf characters, leaf shape and vein pattern are considered the most significant features. However, according to Sadeghi *et al.* (2018), due to the difficulty in observing vein pattern, leaf shape characters are considered more reliable feature than venation. However, relying solely on leaf shape for species characterization may not provide sufficient information since different plant species often have similar leaf shapes. Therefore, additional features such as margin, apex, and base angle are necessary for accurate plant species identification. Nandyal *et al.* (2013), proposed a method for medicinal plant identification based on different shape features as base angle, apex angle, and margin type. The angles and margin types were extracted using computer tools like trigonometric functions and chain codes respectively, resulting in an average recognition and classification accuracy of 98%. Iwata and Saitoh (2013), proposed a tree recognition method utilizing shape and colour features of leaf images. In this method, two leaf images., front and rear leaf images were captured and placed on a white background. Using a graph cuts-based method, leaf region was automatically extracted and sixteen shape features were calculated from this extracted region and fed to a random forest classifier. The results indicated that the recognition accuracy of the rear leaf was higher than that of the front leaf. Munisami *et al.* (2015) developed a method for recognizing images of plant leaves using a mobile app that allowed users to photograph a leaf and upload it to a server. The server then performed pre-processing and used the feature extraction techniques to compare with other databases. Based on the leaf shape, different features were extracted as length and width of the leaf, leaf area, leaf perimeter, leaf hull area and hull perimeter. A k-Nearest Neighbour classifier achieved an accuracy of 83.5% which was further enhanced to 87.3% by incorporating colour histograms. Diaz (2017), addressed the problem of determining leaf shape when dealing with touching or overlapping leaf lobes. This method involved three steps: (1) the acquisition of leaf images using a scanner, (2) performing a two-level image segmentation to create a single binary image, and (3) the contouring and concatenating all binary outlines in a single closed contour accurately reproduced the leaf shape. This approach was particularly useful for capturing the shape of overlapping leaves and for handling rigid and fragile herbarium specimens whose leaves were overlapped and could not be repositioned. because of their rigidity and fragility. Recently, Wu *et al.* (2023) introduced a very effective method for describing leaf shape properties called the improved multiscale triangle descriptor (IMTD). They also explored convolutional features of leaves which were tested on different datasets and achieved a good recognition accuracy. Bowman *et al.* (2023), introduced a tool i.e., MuLES (Multiple Leaf Sample Extraction System) which improved automated study of two-dimensional morphological characters of leaf. The tool is free and easily accessible without requiring coding background and is primarily used to identify simple leaf shapes of plant species and for analysing large plant population very rapidly. The method is also applicable for digital scans of herbarium samples. Montes *et al.* (2024) developed FAMeLeS, fully automated and freely available method to measure leaf morphological traits for very large set of samples and used for very small leaves.

Leaf texture

Texture refers to the surface features of leaf. A leaf can exhibit either smooth or rough texture. Texture is an important feature considered in the field of image processing and computer vision (Metre and Ghorpade, 2013). It depends upon various internal anatomical features of a plant part such as the amount of water in the storage tissue, fibres, vascular bundles, lignin, suberin etc. (Simpson, 2010). Rashad *et al.* (2011), used a method for plant leaf classification based on textural feature using combined classifiers. The proposed system required only a small portion of leaf to study the textural features and hence it could be useful for identifying damaged plants. Using combined classifiers, the correct recognition rate achieved was 98.7% Arun *et al.* (2013), suggested texture feature extraction for the identification of medicinal plants using several classifiers. The accuracy attained was 94.7% with characteristics including grey textures, grey tone spatial dependency matrices (GTSDM), and local binary pattern (LBP) operators. Hidayat *et al.* (2018), also used leaf textures for identification of plants. Several features of leaf (such as area value, shape roundness, perimeter etc.) were taken to identify the texture by backpropagation neural networks, resulting in 97% accuracy. Recently, Chugh *et al.* (2022), introduced a new tool for texture identification from digital images. They used Gray Level Co-occurrence Matrix (GLCM) and metrics such as precision, recall and f-measure to check its performance and achieving accuracies of 94%, 64% and 76%, respectively.

Leaf venation

Leaf venation is a very important feature used for leaf identification. In angiosperms, leaf veins show higher branching pattern characterized by smaller diameter and longer length showing primary (1^o), secondary (2^o), tertiary (3^o), quaternary (4^o), and quinary (5^o) veins (Ash *et al.,* 1999). Vein morphology contain such information which is used for plant classification when the observable differences in shape, colour or texture are lacking. Such features can be instrumental in distinguishing between different varieties of the same species and are often only detectable using automated methods (Grinblat *et al.,* 2016). Such features can be used in distinguishing between different varieties of the same species and are often only detectable using automated methods (Grinblat *et al.,* 2016).

According to Sack and Scoffoni (2013), these branching patterns show different types of vein structures in leaves which help in plant identification. Ambarwari *et al.*(2020), extracted vein features including straightness, angles, length ratios, scale projection, total skeleton length, number of branching points and number of ending points. These features were used to identify plant species using the Support Vector Machine (SVM) technique achieving an accuracy of 84%. Xu *et al.* (2020), researched upon plant leaf vein networks encompassing different orders of veins from primary to secondary and beyond. They evaluated vein segmentation, focusing on the finest veins around 10-20 µm in diameter which could be captured through chemical clearing and staining using light microscope. For high resolution, they developed the LEAFVEIN CNN software, enabling multiscale quantification of leaf vein structures ensuring high accuracy. Grinblat *et al.* (2016), extracted vein features using LEAF Graphical User Interface (LEAF GUI), including total number of veins, nodes and vein width. They used three machine learning algorithms: Support Vector Machines (SVM), Penalized Discriminant Analysis (PDA) and Random Forests (RF), achieving accuracies ranging from 90-95%. Similarly, in another study, Atique *et al.* (2022), studied two deep neural networks: Residual Neural Network (ResNet) and Densely Connected Convolution Network (DenseNet) for vein-based leaf identification. They used two algorithms i.e., Stochastic gradient descent (SGD) and Adam optimization (AO) with ResNet achieving accuracies of 89.24% (SGD) and 89.50% (AO), and DenseNet achieving accuracies of 94.20% (SGD) and 95.72% (AO).

Combined feature based automated identification

The single leaf feature generally does not provide the exact accuracy. Combined leaf features yield more accurate results. Usually, plant leaf identification is done using two methods i.e., multiscale triangle descriptor (MTD) method and local binary pattern histogram Fourier (LBP-HF) method, utilizing shape and texture features respectively. It gives average accuracy of 85.7% with a maximum accuracy of 99.1% (Yang, 2021). Chaki *et al.* (2015) proposed combining leaf texture and shape characteristics with neural classifiers. They used "Curvelet transforms (CT) and invariant moments (IM)" to capture leaf, while complex "Gabor filters (GF) and grey level co-occurrence matrix (GLCM)" were used to capture leaf texture. Asim *et al.* (2023), studied three machine vision classifiers namely, Instant base Identifier (IBI), Random Forest (RF), and Meta Bagging (MB) across twelve varieties of Guava (*Psidium guava*). They considered several leaf features such as leaf shape, texture, blade area and venation and noted significant differences in texture and venation among varieties. IBI outperformed the other two classifiers achieving an average accuracy of 93.01%.

Abdulazeez *et al.* (2021) used visual features including colour, texture, shape, and vein of leaf using a probabilistic neural network (PNN). Shape showed higher performance when using the Centroid-Radii and other features. The automated recognition methods for plant identification based on various leaf features and the accuracy of their results are summarised in the Table 2.

Analysis

The automated plant identification method using leaves depend on extracting various features of the leaf such as leaf shape, texture and venation. For species having similar leaf shapes, additional features such as leaf margin, leaf apex and base angle are used to identify plants more accurately. A recently developed method namely, improved multiscale triangle descriptor (IMTD) has been shown to provide higher accuracy in describing leaf shape. For leaf texture identification methods such as GLCM, GF, Grey texture, GTSDM, LBP are commonly employed. The GLCM is now predominantly used for texture identification. For vein identification SVM, ResNet, DenseNet, CNN, RF are among the most commonly used automated methods.

Conclusion

The leaf serves as the life sustaining photosynthetic organ invariably present in all the land plants. Leaves exhibit numerous structural and surface features that can serve as a crucial taxonomic tool for species identification. The conventional approach of identification takes longer to identify but, undoubtedly produces precise results. Automated methods have utilized overall structure of leaf or one/few significant characters like colour, shape, venation, texture etc. to identify a plant species. Although less accurate than conventional approach, automated technologies require less time to identify plants. The application of leaf-based automated methods has made plant identification easier today. Image based automated identification using a number of neural networks is a faster method and helps narrow down the number of possibilities. Hence, a leaf based computational identification method that relies on a narrowing-down approach can be very much useful for plant identification.

Acknowledgements

The authors thankfully acknowledge the contribution of Mr. S. Ingalhalikar, author of, "Trees of Sahyadri" for stimulating the idea of leaf-based identification of trees. Authors also acknowledge Dr. Nidhan Singh, Associate Professor, Kurukshetra University, Kurukshetra and Shri Prakash Dwivedi, Assistant Professor, Pantnagar University, Pantnagar, for providing the valuable suggestions. All the authors are thankful to Head, Department of Biological Sciences, Dean, College of Basic Sciences & Humanities and Director, Experiment Station for providing the necessary facilities.

Table 1: List of leaf-based identification apps

S. No.	Mobile apps	Features	Pros	Cons	Link of app	Logo
1.	LeafSnap	Popular app Identify with 90% accuracy	Free version, Easy to navigate It has large plant database	Unless pay for premium version, it has constant ads	https://play.google.com/store/apps/details?id=plant.identification.snap&hl=en_IN&gl=US	
2.	PlantSnap	It is a popular app but the accuracy is less than 70%	Free version is there, easy to navigate, large plant database	Unless pay for premium version, it has constant ads and limited to 25 uploads	https://play.google.com/store/apps/details?id=com.fws.plantsnap2&hl=en_IN&gl=US	
3.	Pl@ntNet	Used for wild plants. 85-90% accuracy	Web based version. Free to use and ads free. Mapping feature is there	Smaller database. It has data related to Flora of Nepal and World flora	PlantNet Plant Identification – Apps on Google Play	
4.	iNaturalist	Observation verified by people, experts in their field. 90-95% accuracy	iNaturalist is free to use. Showing worldwide observation and seasonality	Smaller database of animals, plants, fungus, reptiles	https://play.google.com/store/apps/details?id=org.inaturalist.android&hl=en_IN&gl=US	
5.	Seek by iNaturalist	Plant identification upto 60%	Free and ads free, provide common and scientific names, Identify all plants, fungi, and critters	No proper identification. Seek upload photos to iNaturalist. Seek is prepared for children and casual audience	https://play.google.com/store/search?q=seek%20by%20inaturalist&c=apps&hl=en_IN&gl=US	
6.	Picture This	Plant identification up to 98-99% accuracy	Payable app. Recognize more than 10,000 plant species. Plant growing guide, care tips, and water reminder features.	Not found in India	https://play.google.com/store/apps/details?id=cn.danatech.xingseus&hl=en_IN&gl=US	

7.	Google Lens	Automatically installed device, 50% accuracy	Completely free, huge database, constant updates	May not get accurate match; Further research required	https://play.google.com/store/apps/details?id=com.google.ar.lens&hl=en_IN&gl=US	
8.	Plantifier	This app contains many plant species	Free app. Upload a photo and experts will identify	Some technical glitches within the app	https://play.google.com/store/apps/details?id=air.be.trendsco.plantifier&hl=en_IN&gl=US	
9.	Flora Incognita	Identification of more than 4800 plant species	A species profile page provides information like characteristics, distribution of the species. We can save, export, and share the observations on different social media channels	Technical glitches as failed update	https://play.google.com/store/search?q=flora%20incognita&c=apps&hl=en_IN&gl=US	
11.	Garden Answer	Accuracy is less than 20%	Free to use. Identify over 20,000 plants. Gives detail information	Not used for identification for long time	https://play.google.com/store/search?q=garden%20answer&c=apps&hl=en_IN&gl=US	
12.	Verginia tech: Tree identification	It contains fact sheets for 1105 woody plants from all over North America	Free to use. Give description and colour pictures of leaves, flowers, fruits, twigs, bark and form	Not identify live plant image	https://play.google.com/store/search?q=virginia%20tech%20tree%20identification&c=apps&hl=en_IN&gl=US	
13.	iTrees	Covers 50 common tree species found in Mumbai, Kolkata, New Delhi, and Hyderabad	Completely free. Information related to trees and its identification	Do not identify live plant image	https://play.google.com/store/search?q=itrees&c=apps&hl=en_IN&gl=US	

Table 2: List of various automated recognition methods used for plant identification based on different leaf features (2011-2024).

S. No.	Year	Leaf features	Research methods	Result accuracy
1.	2011	Texture	Combined classifiers by using a small part of leaf	98.7% accuracy
2.	2013	Texture	Grey textures, grey tone spatial dependency matrices (GTSDM) and Local Binary Pattern (LBP) operators	Recognition accuracy 94.7%
3.	2013	Leaf shape and margin	Trigonometric and chain code approach	High accuracy of 98% is obtained
4.	2013	Colour and shape	Procrustes method, graph cuts-based method	Recognition accuracy of the rear leaf is higher than front leaf
5.	2015	Texture and shape	Gabor filter (GF) and gray level co-occurrence matrix (GLCM), curvelet transforms (CT) and invariant moments (IM)	Obtained higher accuracy
6.	2015	Shape	KNN, Colour histogram	83.5% and 87.3% accuracy
7.	2015	Color, texture and shape	SVM, NNA, ANN, RF, LDA	Obtain higher accuracy
8.	2016	Vein, number of veins, nodes and vein width.	LEAF-GUI in SVM, PDA, RF.	90-95% accuracy
9.	2017	Shape	Acquisition of leaf images.Two-level image segmentation. Contouring and concatenation	High accuracy of leaf shape
10.	2018	Shape, vein pattern	Naïve Bayes classifier, Decision tree	Average recognition rate was 58.3%
11.	2018	Texture	Backpropagation methods	97% accuracy
12.	2019	Shape and venation	Leaf venation detection technique	Average accuracy by 98.6% and 89.83% for Flavia and Acer.
13.	2019	Leaf pattern	Neural networks such as ANN, PNN, CNN, KNN, SVM	High accuracy about 85-95%
14.	2020	Leaf vein	Support Vector Machine (SVM)	Accuracy was about 84%
15.	2020	Shape, texture	Different methods as ANN, CNN, SVM, KNN	The accuracy is 97%.
16.	2021	Colour, texture, shape, vein	PNN, Centroid-Radii, GLCM	Maximum average accuracy 98.5%
17.	2022	Shape, texture and venation	Deep learning, CNN based LeafNet network, SVM	High accuracy 99.67% and 99.81%
18.	2022	Vein structure	ResNet, DenseNet	ResNet show 89.24%, DenseNet showed 94.20%
19.	2022	Texture	GLCM with metrics precision, recall and f-measure	94%, 64% and 76% accuracy
20.	2023	Leaf shape, length, width, area and aspect ratio	MuLES tool for automated plant identification	Higher accuracy
21.	2023	Leaf shape, texture, blade area, venation.	IBI, RF, MB	93.01%
22.	2023	Leaf shape	IMTD	High accuracy
23.	2024	Leaf morphological traits	FAMeLeS	High accuracy

[Artificial Neural Network (ANN), Convolutional Neural Networks (CNN), Support Vector Machines (SVM), k-Nearest Neighbour (KNN), Probabilistic Neural Networks (PNN), Gabor Filter (GF), Gray Level Co-occurrence Matrix (GLCM), Curvelet Transforms (CT), Invariant Moments (IM), Random Forest (RF), Linear Discriminant Analysis (LDA), Improved Multiscale Triangle Descriptor (IMTD), Instant Base Identifier (IBI), Meta Bagging (MB), Multiple Leaf Sample Extraction System (MuLES), Residual Neural Network-ResNet and Densely Connected Convolution Network (DenseNet).

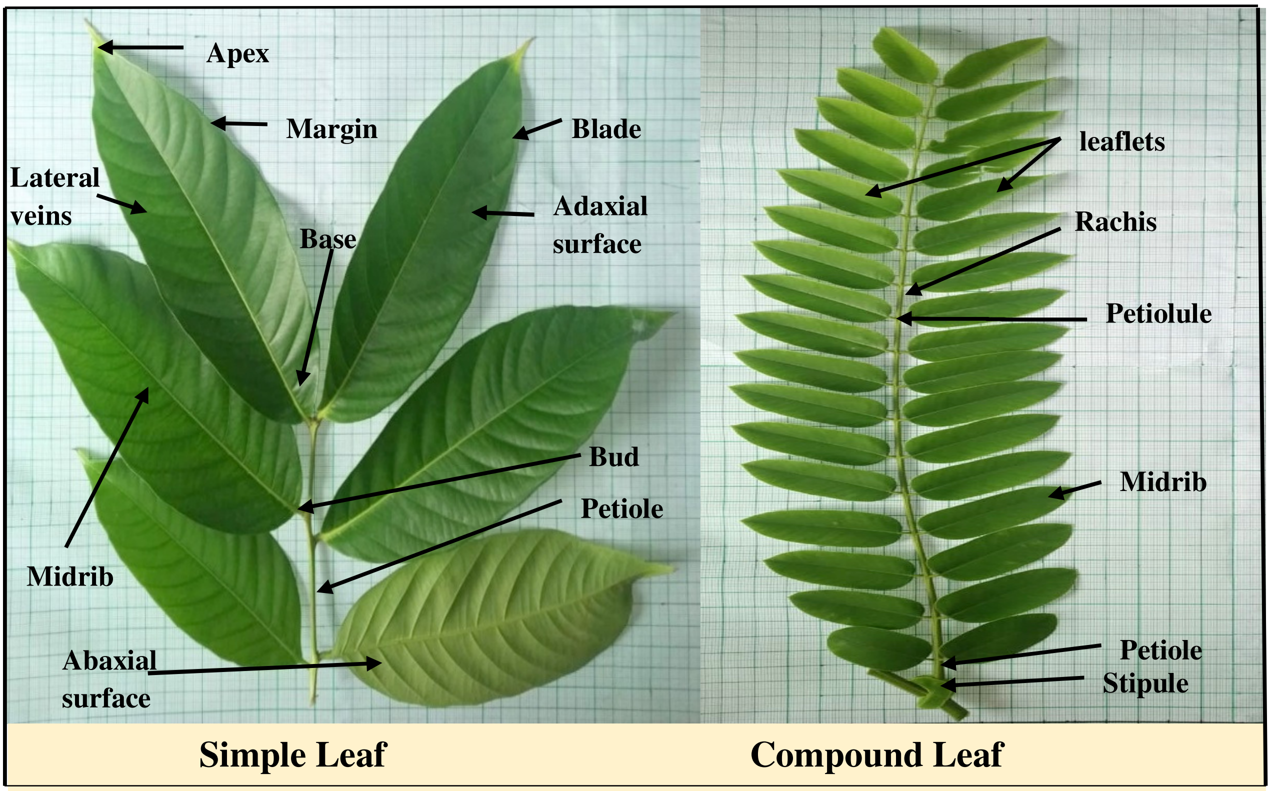

Fig. 1: Simple and compound leaves and their parts

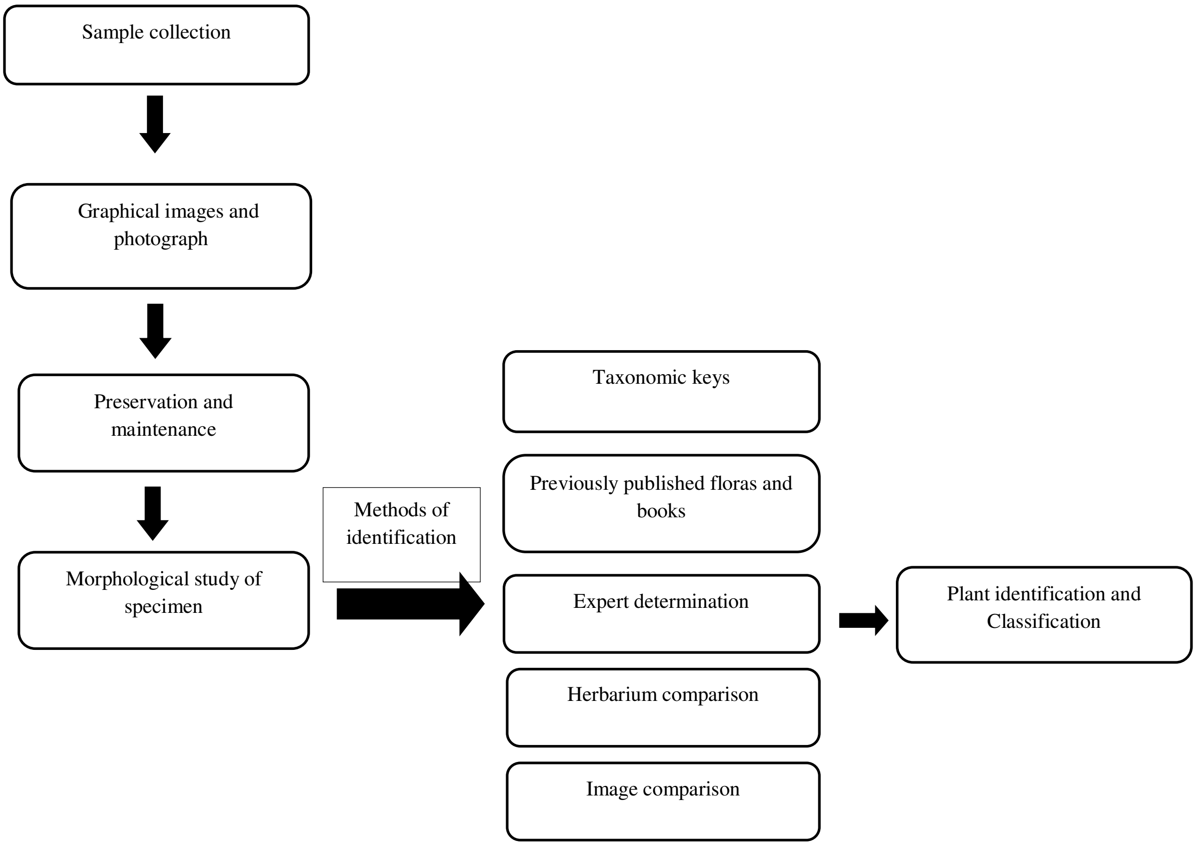

Fig. 2: Steps of traditional identification methods

Flacourtia indica (Burm.f.) Merr.

Delonix regia (Bojer ex Hook.) Raf.

Artocarpus heterophyllus Lam.

Cinnamomum verum J.Presl

Tectona grandis L.f.

Aegle marmelos (L.) Correa

Fig. 3: Images of leaves with graph sheet in background

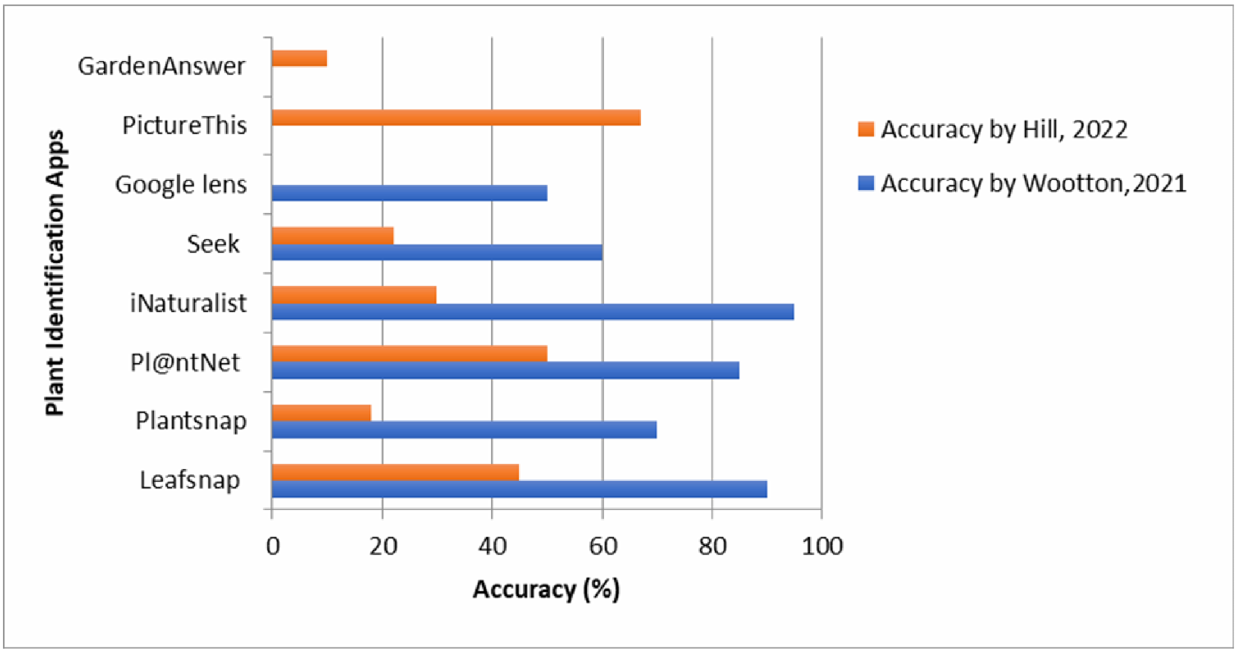

Fig. 4: Overall performance of plant identification apps

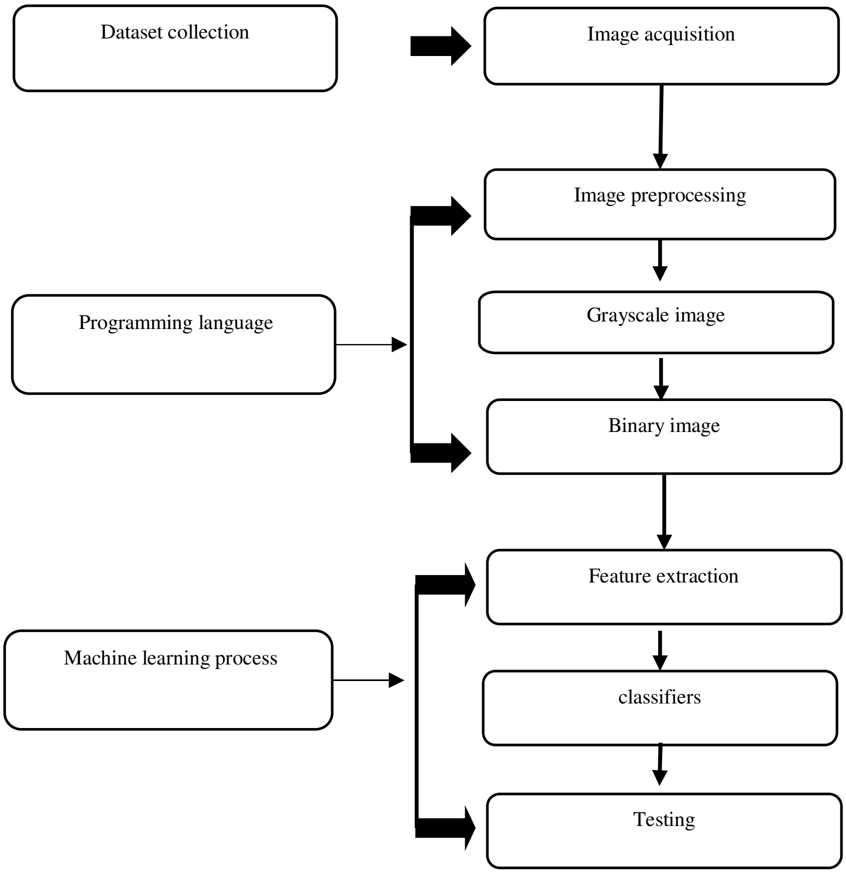

Fig. 5: Steps for automated plant identification

References

Abdulazeez, A.M., Zeebaree, D.Q., Zebari, D.A. and Hameed, T.H. (2021). Leaf identification based on shape, color, texture and veins using probabilistic neural network. *Comput. Syst.,* **25**(3), 617–631.

Agarwal, S.K. (2017). *Flora of Jaunsar Bawar (Chakrata hills, Western Himalaya): with ethnobotanical notes.* Shiva offset press, Dehradun, India.

Ahmed, N., Ghani Khan, M.U. and Asif , S. (2016). An automatic leaf based plant identification system. *Sci. Int.* **28**(1), 427-30.

Ambarwari, A., Adrian, Q.J., Herdiyeni, Y. and Hermadi, I. (2020). Plant species identification based on leaf venation features using SVM. *Indones. J. Electr. Eng*., 330-353.

Arora, V., Rawat, D.S., Singh, A.K. and Chaturvedi, P. (2024). Taxonomical identification of mango (Mangifera indica l.) varieties using leaf morphological characteristics. *Plant Arch.,* **24**(1), 983-990.

Arun, C.H., Sam Emmanuel, W.R. and Durairaj, D.C. (2013). Texture feature extraction for identification of medicinal plants and comparison of different classifiers. *Int. J. Comput. Appl.*, 223-234.

Ash, A., Ellis, B., Hickey, L.J., Johnson, K., Wilf, P. and Wing, S. (1999). *Manual of Leaf Architecture* - morphological description and categorization of dicotyledonous and net-veined monocotyledonous angiosperms. Leaf Architecture Working Group. Washington. 26-44.

Asim, M., Ullah, S., Razzaq, A. and Qadri, S. (2023). Varietal discrimination of guava (*Psidiumguajava*) leaves using multi features analysis. *Int. J. Food Prop*., **26**(1), 179-96.

Atique, A., Karim, S., Shahid, S. and Alamgir, Z. (2022). Identification of plant species through leaf vein morphometric and deep learning. *Pak. J. Bot*., **54**(6), 2195-202.

Azlah, M.A.F., Chua, L.S., Rahmad, F.R., Abdullah, F.I. and Wan Alwi, S.R. (2019). Review on techniques for plant leaf classification and recognition. *Comput*., **8**(4), 77.

Beikmohammadi, A., Faez, K. and Motallebi, A. (2022). SWP-LeafNET: A novel multistage approach for plant leaf identification based on deep CNN. *Comput. Electron. Agric*., 202, 117470.

Bridson, D. and Forman, L. (1998). The herbarium handbook. 3rd ed. Royal botanic garden, kew.

Bowman, C.S., Traband, R., Wang, X., Knowles, S.P. and Lo, S. (2023). Multiple leaf sample extraction system (MuLES): a tool to improve automated morphometric leaf studies. *Appl. Plant Sci*., 1-7.

Carpentier, M., Philippe, G. and Gaudreault, J.A. (2018). Tree species identification from bark images using convolutional neural networks. 2018.

Chaki, J., Parek, R. and Bhattacharya, S. (2015). Plant leaf recognition using texture and shape features with neural classifiers. *Pattern Recognit. Lett*., **58**, 61–68.

Chanyal, H., Yadav, R.K., Saini, D.K. (2022). Classification of medicinal plants leaves using deep learning technique: a review. *Int. J. Intell. Syst. Appl. Eng*. **10**(4), 78-87.

Chugh, H., Garg, M., Gupta, S., Sharma, S. (2022). Plant leaf image identification with texture features using microstructure descriptor, 2022 10th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO), Noida, India, 2022:1-5.

Diaz, G. (2017). Contour recognition of complex leaf shapes. *PloS One*. **12**(12).

Duda, R.O., Hart, P.E. and Stork, D.G. (2006). Pattern classification. 2nd ed. Wiley, New York. 1-18.

Duthei, J.F. (1903). Flora of upper gangetic plain and of the adjacent siwalik and subhimalayan tracts. BSI, Calcutta.

Faizal, S. (2022). Automated identification of tree species by bark texture classification using convolutional neural networks. Comput. *Vis. Pattern Recognit*. **10**(9), 11.

Fiel, S., Sablatnig, R. (2010). Automated identification of tree species from images of the bark, leaves or needles. Computer vison lab.

Gamit, E. (2015). Literature review on plant leaf classification. *Int. Res. J. Eng.Technol*., **1**(2): 4-6.

Gaur, R.D. (1999). Flora of the district Garhwal, north west Himalaya: With ethnobotanical notes. Trans media, Srinagar (Garhwal).

Grinblat, G.L., Uzal, L.C., Larese, M.G., Granitto, P.M. (2016). Deep learning for plant identification using vein morphological patterns. *Comput Electron Agric.* **127**, 418-24.

Gujar, H., Chile, S., Shitole, S., Mhatre, P., Kadam, S., Mittal, U. Python based image processing. Conference: Avishkar 2015 at Pune. 2016.

Gschwantner, T., Schadauer, K., Vidal, C., Lanz, A. (2009). Common tree definitions for national forest in ventories in europe. *Silver fennica*, **43**(2).

Gupta, R.K. (1968). Flora Nainitalansis: A handbook of flowering plants of Nainital. Navayug traders, New Delhi.

Hardin, J.W., Leopold, D.J., White, F.M. (1929). Harlow and Harror's textbook of dendrology.9th ed. McGraw Hill,Amerika, Newyork.

Hassoon, I.M., Kassir, S.A., Altaie, S.M. (2011). A review of plant species identification techniques. *Int. J Sci. Res.*, **7**(8), 325-328.

Hasna, K.P. and Jithendra, K.B. (2020). A review on plant species recognition based on leaf images. *Int. Res. J. Eng.Technol*. **7**(11), 1273-1276.

Hidayat, T., Nilawati, A.R. (2018). Identification of plant types by leaf textures based on the backpropagation neural network. *Int. J. Electr. Comput. Eng*. **8**(6), 5389-5398.

Hill, E. (2022). Plant identification apps. MSU Extension.2022. https://www.educationalappstore.com.

Hussain, S., Nanda, S., Zhang, J., Rehmani, M.I.A., Suleman, M.G., Hou, H. (2021). Auxin and cytokinin interplay during leaf morphogenesis and phyllotaxy. *Plants*. **10**(8), 1–14.

Iwata, T., Saitoh, T. (2013). Tree recognition based on leaf images. 'In: Intrumentation, control, information technology and system integration' SICE annual conference at Japan. 2489-94.

Ingalhalikar, S. (2020). Leaf-based identification for trees of Sahyadri. Corolla publications, Pune. 2020.

Jones, S.B. and Luchsinger, A.E. (1986). Plant systematics. library of congress. United state of America; 1986. p. 188-215.

Kaur, S. and Kaur, P. (2019). Plant species identification based on plant leaf using computer vision and machine learning techniques. *Int. J. Multimed. Inf*., **6**(2), 49-60.

Krishen, P. (2006). Trees of Delhi. A field guide. Replika Press Pvt. Ltd., India.

Krishen, P. (2013). A field guide for tree spotters jungle trees of central India. Penguin random house India Pvt. Ltd., Haryana, India.

Metre, V. and Ghorpade, J. (2013). An overview of the research on texture-based plant leaf classification. *Int. JComput. Sci. Network*. 2.

Munisami, T., Ramsurn, M., Kishnah, S., Pudaruth, S. (2015). Plant leaf recognition using shape features and colour histogram with K-nearest neighbour classifiers. *Procedia Comput. Sci*., **58**, 740–7.

Naithani, B.D. (1984a). Flora of Chamuli vol 1. BSI, Calcutta; p. 1-380.

Naithani, B.D. (1985b). Flora of Chamuli vol 2. BSI, Raje printers, Rameshnagar, New Delhi; p. 381-791.

Nandyal, S.S., Anami, B.S., Govardhan, A. (2013). Base and apex angles and margin types-based identification and classification from medicinal plants' leaves images. *Int. J. Comput VisRobot*., 3(3), 197–224.

Osmaston, A.E. (1927). A forest flora for Kumaun. Gov. press, united provinces, Allahabad, India. 1927.

Pradhan, P.P. and Nayak, S.K. (2021). Digital image processing in various tools. *Int. J. adv. Eng. Technol*., **12**(3), 1502-5.

Pusalkar, P.K., Srivastava, S.K. (2018). Flora of Uttarakhand, gymnosperms and angiosperms (Ranunculaceae-Moringaceae). BSI, Kolkata.

Rashad, M.Z., el-Desouky, B.S., Khawasik, M.S. (2011). Plants images classification based on textural features using combined classifier. *Int. J. Comput. Sci. Inf. Technol. Res*., **3**(4), 93–100.

Ratajczak, R., Bertrand, S., Crispim-junior, C.F., Tougne, L. (2019). Efficient bark recognition in the wild. International conference on computer vision theory and applications.

Rzanny, M., Seeland, M., Waldchen, J. and Mader, P. (2017). Acquiring and preprocessing leaf images for automated plant identification. *Plants Methods*. **97**(13), 3-12.

Sack, L., Scoffoni, C. (2013). Leaf venation: structure, function, development, evolution, ecology and applications in the past, present and future. *New Phytol*. **198**(4), 983–1000.

Sadeghi, M., Zakerolhosseini, A., Sonboli, A. (2018). Architecture-based classification of plant leaf images. *Comput. Sci*., 2018;12.

Simpson, M.G. (2010). Plant systematics. 2nd ed.Dana dreibelbis, Canada. 2010.

Singh, G. (2010). Plant systematics, an integrated approach. 3rd ed. Science publishers, India. 2010.

Sulc, M. and Matas, J. (2017). Fine grained recognition of plants from images. *Plant Methods.* **13**, 115.

Sumathi, C.S., Kumar, A.V.S. (2014). Neural network based plant identification using leaf characteristics fusions. *Int. J. Comput. Appl*., **89**(5), 31-5.

Szejner, M., Emanuelli, P. (2016). Tree species identification in the tropics. In book: Tropical forestry handbook., 451-70.

Waldchen, J., Mader, P. (2017). Plant species identification using computer vision techniques: A systematic literature review. *Arch.Comput. Methods Eng*., **25**, 507–43.

Wojtech, M. (2011). Bark: A field guide to trees of the northeast. University Press of New England, China. 2011.

Wootton, K. (2022). Using technology for plant identification.2021. https://youtu.be/pYv8Y1RbFUc. Accessed 05 oct 2022.

Wu, Q., Zhou, C., Wang, C. (2015). Feature Extraction and Automatic Recognition of Plant Leaf Using Artificial Neural Network. 2015.

Wu, H., Fang, L., Yu, Q., Yuan, J. and Yang, C. (2023). Plant leaf identification based on shape and convolutional features. *Expert Syst. Appl.,* **219**, 119626.

Xu, H., Blonder, B., Jodra, M., Malhi, Y., Fricker, M. (2020). Automated and accurate segmentation of leaf venation networks via deep learning. *New Phytol.* **229**(1), 631-48.

Yang, C. (2021). Plant leaf recognition by integrating shape and texture features. *Pattern Recognit*. **112**, 107809.

Youngentob, K.N., Zdenek, C., Gorsel, E. (2016). A simple and effective method to collect leaves and seeds from tall trees. *Methods Ecol. Evol*. **7**(9), 1119-23.

Plants of the World Online. Facilitated by the royal botanic gardens, Kew. 2023. http://www.plantsofthe worldonline. org/ POWO.Accessed18 Jan 2023.

International Plant Names Index. The royal botanic gardens, Kew, Harvard university herbaria andlibraries and Australian national herbarium. 2023. http://www.ipni.org/ IPNI. Accessed 18 Jan 2023.

Database of Indian Plants - developed by the members of Efloraindia, Botanical Survey of India. 2014.https:// efloraindia.bsi.gov.in/eFloraindia. Accessed 18Jan 2023.