A comparison of accuracy of image recognition apps for identification of segetal and ruderal flora

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Graduate thesis

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1. Introduction

In agricultural and natural ecosystems, weeds have long been a problem that must be dealt with since they pose a serious danger to crop production, biodiversity, and the health of the ecosystem as a whole. Segetal and ruderal weeds are two important categories that stand out among the various types of weeds, each having a unique impact on the environment and agriculture. Arable weeds, often referred to as segetal weeds, flourish in cultivated fields where they compete with crops for resources, resulting in considerable production losses. Ruderal weeds, on the other hand, are opportunistic, living in disturbed or abandoned locations, and frequently act as markers of ecological deterioration. For efficient weed control and sustainable land management, segetal and ruderal weeds must be accurately identified and managed. In the past, weed identification required labor-intensive, manual techniques that involved specialists examining and categorizing plants based on physical characteristics. This method's limitations, meanwhile, include its length, subjectivity, and reliance on the knowledge of certain persons (Mendes et al., 2020). Additionally, when dealing with huge weed populations, various species, and differences in development phases, the identification procedure becomes more difficult. Recent developments in technology have created new opportunities for automating the weed detection process, particularly in the area of combining machine learning and computer vision techniques for picture recognition. Applications for image identification have gained attention as potential tools to assist farmers and academics in identifying weeds reliably and quickly. These applications are powered by machine learning algorithms that can swiftly analyze massive volumes of picture data (Mangina et al., 2022). With the use of these applications, manual weed detection might take less time and effort, allowing for quicker action. High weed identification accuracy is essential for preventing mismanagement, which can have serious economic and environmental repercussions.

1.1. Research goal

This paper's research goal is to find out whether smartphone plant identification apps can identify weeds and to compare the apps to see which one is the most accurate.

2. Literature review

The usefulness and dependability of several image recognition applications in the context of weed identification were examined in prior research on a topic related to the one covered in this work. Numerous studies have examined how well programs work while taking into account elements like accuracy, speed, and usability. For instance, Siddiqua et al. (2022) and also Mäder et al. (2021) compared several image recognition software in thorough research and discovered that although some systems had good accuracy rates for weed identification, others had difficulties with particular species or environmental factors. Additionally, Peteinatos et al. (2020) looked at the deep learning techniques utilized by a few of the apps, emphasizing the value of neural network designs and training datasets in producing reliable results. The algorithm provides a prioritized list of the most pertinent species together with a varied collection of representative photographs of each analyzed species. Sfar et al. (2013) developed a novel technique based on several leaf images of the same plant. Although they concentrate on leaves, their approach is general and is built on a hierarchical representation of latent variables known as identification keys, which convey the domain's understanding of taxonomy and landmarks. The keys are assessed in order for each query image, going from the landmark to the genus and then to the predicted species set. A single ranked list of species is then created from the results of all the searches. Studies demonstrate that the suggested method performs superbly on a number of pure leaf image collections and offers a clear user interface for determining species diversity.

Although there are image-based identification systems, they typically use hand-crafted algorithms to extract feature sets chosen beforehand to identify species of certain taxa. As a result, these systems are restricted to particular taxa and need the assistance of specialists who can give taxonomic expertise to create such specialized systems. In their paper, Barre et al. (2017) set out to create a deep learning system that would be able to identify different plant species by using classifiers and discriminative features learned from photos of leaves. It is demonstrated that feature learning using a convolutional neural network (CNN) may produce better feature representation for leaf photos than hand-crafted features by comparing the results with specialized systems like LeafSnap. LeafSnap, a smartphone application for automatic tree identification, was released to the public in 2011. Over the first three years, the app was downloaded by over 1.5 million users from five continents and 181 countries, who shot over 3 million photographs of leaves. The high levels of identification accuracy achieved by LeafSnap, as confirmed by experienced botanists, have been used to map the global distribution of native and invasive species at a scale previously unattainable without this technology and the assistance of citizen scientists. Species have migrated or changed little from predicted distributions in the 1950s. Kress et al. (2018) conclude that this app, which is used on millions of phones, has the potential to collect invaluable data that can be used to monitor the effects of climate change and exotic species on the distribution of trees at wide geographic scales.

Reda et al. (2022) created a mobile plant care assistance system (AgroAId) that uses computer vision technology to identify a plant combination from an input image of plant leaves, recognizing 39 classifications. A comparative study is used to maximize the performance of a multi-label classification model and to identify the effects of changing the convolutional neural network (CNN) architecture, transfer learning methodology, and hyperparameter tuning. Four lightweight mobile-optimized CNNs were tested in four transfer learning scenarios. The simplest high-accuracy model was determined to use a fully retrained basic network with optimized hyperparameters, attaining an accuracy of 99% and demonstrating the usefulness of the proposed approach. It's part of the plant care support system, together with a mobile app and a central cloud database. In addition, the system employs user collective classification data to provide spatiotemporal analysis on regional and seasonal disease trends, making these analytics available to all system users in order to raise awareness of global agricultural trends.

Bilyk et al. (2020) examined mobile plant identification applications such as Flora Incognita, PlantNet, PlantSnap, PictureThis, LeafSnap, and Seek in terms of usability factors and identification accuracy. They provided a usability analysis, as well as a poll of digital education specialists on the simplicity of installation, level of interface accessibility, and picture processing accuracy. Flora Incognita and PlantNet have shown to be the most useful and informative plant identification application interfaces. They were, however, marked by much inferior accuracy when compared to Google Lens results. A comparison of the usability of the applications examined with Google Lens demonstrates that Google Lens has greater usability, and so the same authors recommend the Google Lens application for plant identification the most.

Bonnet et al. (2016) presented intriguing research in which they detail an experiment aiming at comparing the performance of cutting-edge computer vision systems in plant identification to human competence. As a result, a subset of the evaluation dataset used in the 2014 LifeCLEF Plant Identification Challenge was disseminated to volunteers with varied levels of knowledge, ranging from leading experts in the target flora to inexperienced test subjects. A total of 16 human runs of LifeCLEF tasks were gathered and compared to 27 machine-based trials. One of the most important findings of the experiment is that the devices are still a long way from outperforming the finest expert botanists in image-based plant identification competitions. The best machines, on the other hand, compete with professional botanists and clearly outperform novices and unskilled examinees. This demonstrates that automated plant identification systems operate well and may pave the way for a new generation of environmental monitoring technologies.

Many approaches exist to eliminate plant blindness, and the majority of them consider plant identification as the key to preventing it. Plant species identification is a regular activity in botany classrooms, and it can be entertaining to a wider audience. Plant identification can be viewed as a lifelong talent that can be learnt during formal education. There are various methods for identifying plants, the majority of which rely on identification keys that are available in print or online. Traditional plant identification methods include dichotomous, polytomous, and image-based identification keys. Identification keys were converted to digital and interactive formats, and more recently to smartphone formats, with the introduction of computers (Land and Šorgo, 2022).

The goal of Lang and Šorgo (2022) study was to determine the added value of the PlantNet program when compared to the usage of traditional printed image-based identification keys and unstructured Internet searches. They compared the three techniques' identification outcomes and accuracy. They also demonstrated differences in perceived barriers and student satisfaction among the three techniques. The satisfaction with plant identification based on mobile technology, which can be considered a bridge to prevent plant blindness, was of particular interest. The students were tasked with identifying six plant species. Two with the use of a book, two with the assistance of the Internet, and two with the assistance of PlantNet. Following completion of the exercise, the differences between the three techniques were assessed. Students were also polled on how tough they thought the task was. It was discovered that students prefer the book. When asked which implementation of plant identification they had the least difficulty with, 59.3% of respondents said they had the least problems with the PlantNet program. They had the most difficulty identifying plants on the Internet (79.1%). When asked which technique of identification they would use if they could, 54.7% said they would use a book to identify the plant. Students also ranked plant identification methods on a scale of one to three, with one being the easiest and three being the most difficult. Based on their experience with all approaches, they found that the PlantNet application is the easiest way to identify plants, and the Internet is the most challenging.

2.1. Segetal flora

Segetal flora is a very significant part of the plant kingdom that is directly linked to human endeavors, particularly with agriculture and land development. This flora refers to plant species that naturally grow as weeds or as wild plants in places like fields, plantations, and other cultivated environments. Segetal plants have an important influence on ecosystems and agricultural methods, while frequently being ignored or even repressed by farmers (Petit et al., 2011). The vitality of the segetal flora is one of its primary features. Segetal plants are flexible and procreate fast, frequently employing tactics like mass seed production or speedy regrowth from buried seeds. This trait makes plants resistant to a variety of farming techniques, but it can also make weed management difficult for farmers. The segetal flora also has ecological importance. Some of these plants can act as hosts for helpful insects that promote pollination, such bees and ladybugs (Hole et al., 2005). Additionally, because they are homes for numerous birds, insect, and other species, segetal plants help to preserve biodiversity. In his work, Grime (2001) highlights the significance of seed-bearing species in community dynamics, highlighting their aggressive and competing behaviors. Additionally, Zimdahl's research (2007) examined the complex dynamics of competition between segetal flora and crops, underlining the crucial part played by segetal species in weed control tactics. Since it provides insights into ecosystem resilience, biodiversity protection, and crop management methods in the face of escalating environmental difficulties, understanding the dynamics of plant flora is still crucial in the context of modern agriculture.

2.2. Ruderal flora

A vital element of urban ecosystems, ruderal flora is made up of an amazing variety of plant species that have evolved to survive in disturbed settings and benefit from human-caused disruptions. Ecologists, urban planners, and environmentalists are all very interested in these opportunistic plants since they are crucial to ecological succession and ecosystem resilience. Ruderal species are frequently distinguished by their capacity to live in disturbed environments with high levels of human activity, such as abandoned lots, building sites, roadsides, and other disturbed places. These plants have a variety of adaptive characteristics, including quick germination, effective resource usage, and pollution tolerance, which all help them outcompete other vegetation in urban areas. They are crucial to comprehending urban and regeneration ecology because of their capacity to endure and even dominate in such difficult conditions. In particular, ruderal flora can operate as a marker of environmental change by demonstrating the effects of urbanization and provide important information about the condition of urban ecosystems (McDonnell and Hahs, 2008). Additionally, they support a range of wildlife, including insects, birds, and small mammals, by providing habitats and supplies (Hope et al., 2003). It is impossible to undervalue the contribution of ruderal flora to ecosystem health. According to D'Antonio and Meyerson (2002), the ruderal flora has the power to swiftly reestablish vegetation in damaged areas and aids in soil stabilization, erosion prevention, and the control of invasive species. Additionally, because to their dynamic nature, ruderal communities may have an impact on the soil microbiota and nutrient cycling, which may have an impact on larger-scale ecosystem processes (Leff et al., 2018). Urban planners and environmentalists looking for long-term solutions for urban green areas are placing more and more emphasis on the resilience and adaptation of ruderal species as urbanization spreads around the globe (Fischer et al., 2013). Ruderal flora management and conservation in urban habitats provide both possibilities and problems. Despite the fact that some of these species are invasive and may endanger local biodiversity, others may be crucial to sustaining native animals and enhancing urban green infrastructure. In order to increase urban biodiversity and ecological resilience, there is growing interest in creating a balance between native and non-native ruderal plants (Lundholm, 2009). Ruderal flora is a vital and dynamic part of urban ecosystems, acting as major agents in ecological succession, markers of ecological change, and contributors to urban biodiversity.

2.3. *Calystegia sepium* L.

Hedge bindweed (*Calystegia sepium* L.) is a perennial herbaceous plant from the Convolvulaceae family. The stem, which may reach a length of three meters, expands by encircling adjacent plants. The well-developed root is branching. The leaves are pointed at the top, profoundly arrow-shaped, and 5 to 10 cm long by 3 to 7 cm broad with a complete but slightly wavy margin. The blooms are solitary, huge, funnel-shaped, and white (Figure 1). They are situated in the axils of the top leaves on long stalks that are longer than the leaf petioles. From June through September, when it blooms, bees come to collect pollen and nectar. The fruit is shaped like a quiver and has three to four 5 mm long, ovoid, black seeds within. Each year, a single plant produces 100–400 seeds, which typically germinate in the spring. It spreads by the germination of seeds, roots, and aerial shoots that touch the ground and take root. It is found across temperate parts of the planet. From the lowlands to the mountains, it thrives on rich, loose soils that are damp and humid. It can be found on abandoned locations, along highways, on forest borders, along rivers and streams, and on agricultural land, in vineyards, and orchards (Knežević, 2006). It resembles the field bindweed (*Convolvulus arvensis* L.), but the hedge bindweed has longer leaves, two blooming leaves, and all-white flowers.

Figure 1. Hedge bindweed - *Calystegia sepium* L. (Source: Bilić, D., 2023)

2.4. *Papaver rhoeas* L.

The annual herbaceous plant common poppy (*Papaver rhoeas* L.) belongs to the Papaveraceae family of poppies. Upright, simple or sparsely branched, the stem can reach a height of 80 cm. It has hairs on it and has milky-white fluid within. The leaves are hair-covered, oblong and lanceolate, simple or double-lobed. Upper leaves are sessile, whereas lower leaves are on petioles. The solitary, huge, up to 10 cm in diameter blooms are coated in bristly hair and grow on the tops of the stalks. They feature many stamens, two green lobes that swiftly fall off the calyx, and bright crimson, fragile petals with conspicuous black dots at the base. They flower from May to July, during which time bees come to visit and bring back a lot of blue pollen. The fruit is an oval capsule that is 1-2 cm long and has 7-9 compartments at the top that are filled with many tiny, dark-brown seeds. In one season, a single plant may generate 10 000-20 000 seeds, each of which has a 10-year germination window (Knežević, 2006). It naturally grows in northern Africa, western Asia, and Europe. It spreads as a weed on meadows, fields, and environments with a rough surface (Figure 2). It grows quickly from seeds and prefers damp, nitrogen-rich soil. In addition to the seeds being used as a spice in cakes and pastries, the young leaves of the ground rosette are edible. About 35% of the seeds' weight is made up of fatty oil, the majority of which is linolenic acid (69%). Coughs can be treated with tea or syrup made from the flower petals. The plant does not contain opium alkaloids, in contrast to the closely related garden poppy (*Papaver somniferum* L.), and serious poisonings from the plant have not been documented (Maretić, 1986).

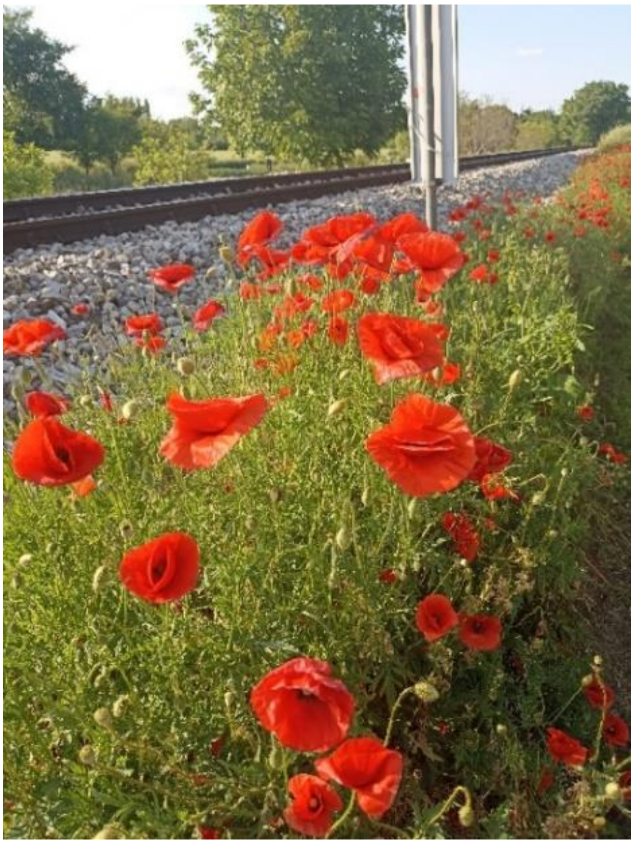

Figure 2. Common poppy - *Papaver rhoeas* L. (Source: Bilić, D., 2023)

2.5. *Anagallis arvensis* L.

An annual herbaceous plant from the primrose family (Primulaceae), scarlet pimpernel (*Anagallis arvensis* L.) is depicted in Figure 3. The stem is prostrate, low-growing, 10 to 25 cm tall, branching, four-edged, and naked. It has a spindle-shaped root. The ovate, 1-2 cm long and opposing. They lack a stem, have a sharp edge, and are hairy on the back. Small, solitary blooms are borne on slender stalks that protrude from the leaf axils. Five orange (occasionally bluish) spherical petals make up the corolla. The tops of the petals are widely rounded, and the front edge is thickly glandular hairy, whole, or faintly serrated (Knežević, 2006). Five stamens are present. They are in bloom from June to September, although the blooms close in inclement weather and at dusk. The fruit is a spherical capsule with one flap that unfolds to reveal countless tiny seeds. Each year, a single plant can generate 100 – 300 seeds, which can continue to germinate for up to 5 years. Although it is natively found in North Africa, Western Asia, and Europe, it is now regarded as domesticated all over the world. Its natural habitats range from lowlands to foothills at 1500 meters above sea level and consist of sunny areas with lawns, fields, arable land, and humus lands. Wheat flour and bread have a dark hue thanks to the seeds that are crushed with it. It is seen as a slightly poisonous plant. It has cyclamen in the roots and saponins in the herbaceous portions. Due to its bitter flavor, grazing animals often avoid it, but if there is a lot of it, they could eat it. Even birds can be fatally poisoned by the seeds, according to reports of sheep being poisoned (Forenbacher, 2001).

Figure 3. Scarlet pimpernel - *Anagallis arvensis* L. (Source: Bilić, D., 2023)

2.6. *Ambrosia aremisiifolia* L.

The annual herbaceous plant known as common ragweed (*Ambrosia artemisiifolia* L.) belongs to the family Asteraceae. The stem may reach a height of 150 cm, it is erect, four-edged, branching in the top section, and coated with coarse hairs. The root is shallow, robust, and wiry. As seen in Figure 4, the leaves are opposite, elliptical, 5 to 10 cm long, strongly pinnately split, densely covered with nearby hairs, and bluish-green in color, with a darker front and a lighter reverse. The monoecious blooms grow in erect clusters at the ends of the stems and side branches. The male flowers are situated above the female blooms, which are found in the axils of the top leaves. The carpel is expanded, and there are 5 stamens. They are flowering from July through September. A fruit (achene) is around 3 mm in size. Each plant releases hundreds of millions of pollen grains in a single season, and male flowers generate a lot of pollen that is carried by the wind more than 300 kilometers. The plant may generate up to 6 000 seeds each year, and they can remain viable for more than 30 years. It was brought to Europe in the 19th century via import from North America (Knežević, 2006).

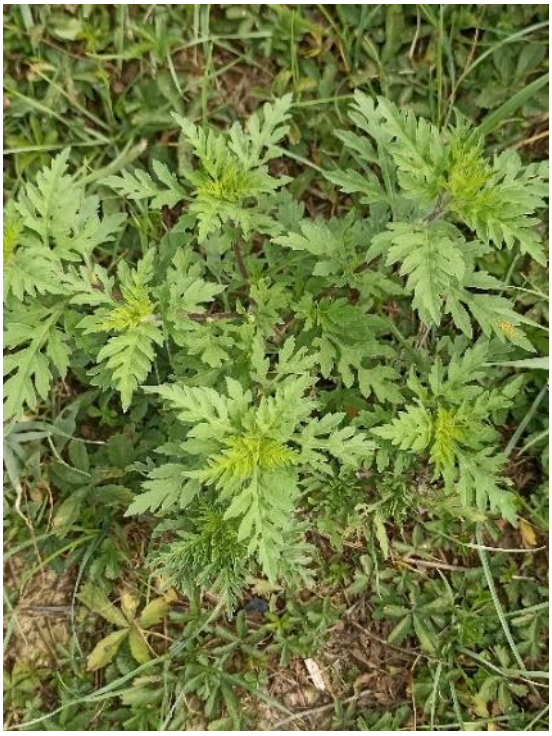

Figure 4. Common ragweed - *Ambrosia artemisiifolia* L. (Source: Bilić, D., 2023)

It spreads swiftly, grows along highways, on unused areas and meadows, among crops in the field, and in flower beds in the garden. It is one of the most invasive plants. It starts growing in April and has a terrible name for being one of the worst allergies. However, in August, when it is in the blooming stage, problems arise. It is said that ragweed produces more pollen overall in a season than all other plants combined, with the exception of grasses. An allergy can be brought on by as little as 20–30 pollen grains per square meter. Nasal congestion, sniffling, sneezing, and red, itchy eyes are symptoms. Many people get allergic responses as a result of its robust, invasive reproduction. During the ragweed flowering season, ragweed avoidance is advised (Knežević, 2006).

2.7. *Prunella vulgaris* L.

Prunella vulgaris L. (common selfheal) is a perennial herbaceous plant belonging to the Lamiaceae family (Figure 5).

Figure 5. Common selfheal - *Prunella vulgaris* L. (Source: Bilić, D., 2023)

The stem is mainly branching, up to 30 cm tall, and either hairless or coated with scant hairs. The root is compact and fully formed. The leaves are ovoid and elongated, the stem leaves are opposing, the ground leaves are on the petioles and form a ground rosette, and they are up to 5 cm long, 0.5-2 cm broad, with prominent veins and sparsely coated in hairs. The monoecious flowers have a length of 1-1.5 cm, are arranged in 4-6 clusters in what appear to be whorls, and are tightly clustered in upright panicles just above the top leaves. The corolla is double-lipped, purple-blue or, less frequently, white, with an upper upright lip and a lower three-parted lip. The calyx features five extremely small, sharply cut teeth on its top lip, is bell-shaped, double-lipped, and coated in unusual hairs. There are four stamens, two of which are on the longer filaments of the stamens. Below the anther on the longer filaments of the stamens is a filament tooth. The plants flower from June through September. The fruits are ovoid to elliptical nuts. Each year, one plant can yield up to 350 of these seeds. It is a common species in Europe, Asia, and North Africa, and is regarded as domesticated elsewhere. On moist lawns, meadows, pastures, arable land, and vineyards, it typically grows in big groups. Although it is a poor choice for grazing animals, it is a fantastic plant for making honey. The young leaves can be cooked like spinach or eaten raw as a salad (Knežević, 2006).

2.8. *Convolvulus arvensis* L.

Convolvulus arvensis L. (field bindweed) is a perennial herb belonging to the morning glory family (Convolvulaceae). The root system typically extends up to 10 cm below the surface, but it can extend deep into the ground and be up to 3 meters long. The stem is up to 2 meters long, branching, slender, and naked. It spreads by crawling across the ground, wrapping itself around a fence, or around other plants in a counterclockwise direction. On somewhat long petioles simple, alternating, lanceolate leaves that get narrower as they go closer to the top of the stem are arranged. As shown in Figure 6, the blooms are trumpet-shaped, light pink or white, and measure around 2-3 cm in diameter. They are generally found alone on the stalks. The plants are flowering from June through September. Although new blooms are continually being produced, the flowers themselves have a relatively brief lifespan; they open in the morning but have already bloomed by midday. The fruit has four valves and is shaped like a quiver. It has two black seeds within. Up to 500 seeds from a single plant can remain viable for up to 20 years (Knežević, 2006). Field bindweed has expanded widely over other regions in addition to its original distribution in Europe and Asia. The best habitats are rich, well-drained soils that are sunny and humid. It may be seen growing in fields and alongside highways. In the garden, it is a robust weed that suffocates nearby stalks by wrapping itself around them. Seeds and root fragments are used in its propagation. It is a fantastic honey plant since it provides pollen and nectar for bees. It is said to make milk fattier since cows enjoy eating it. Young leaves may be used in soups and stews and are edible.

Figure 6. Field bindweed - *Convolvulus arvensis* L. (Source: Bilić, D., 2023)

2.9. *Xanthium strumarium* L.

Rough cocklebur (*Xanthium strumarium* L.), an annual herbaceous plant from the genus *Xanthium* of the Asteraceae family with opposite leaves, a bushy appearance, and wiry roots is presented in Figure 7. The branches and stem are quite rough and frequently feature brownish or purple splotches or stripes. Alternate, ovate to triangular-shaped leaves are on a long stem. The leaves are whole or have a few sparsely serrated lobes; they are green; and the upper and bottom sides bear short, stiff hairs. Unisexual and monoecious, the blooms grow in inflorescences. The highest portion of the stalk contains the male flowers, which have a single row of sheathing leaves. Below these, in the leaf axils, are the female flowers. The filaments of the five fused stamens, which are present, are joined to the corolla. It is pollinated by the wind and blooms in the months of July and August. The fruit is an egg-shaped quiver that is approximately 2 cm long and coated in numerous spines. It is initially green and becomes dark brown as it ripens (Fan et al., 2019). It thrives in warm, sunny environments. It frequently grows along the sides of roadways, along farmed fields, and along railroad and road embankments. The common weevil competes with agricultural crops like cotton and soybeans, spreads infections to horticulture plants, and contaminates agricultural crop seeds, all of which have significant negative economic effects. Pigs, sheep, and cattle are extremely poisonous to it. In addition to harming cattle, it may taint wool (Knežević, 2006).

Figure 7. Rough cocklebur - *Xanthium strumarium* L. (Source: Bilić, D., 2023)

3. Materials and methods

The weed flora was identified using mobile identification applications. PlantNet, Blossom, PlantIn, Plantum, and PlantMe are the mobile identification tools utilized in the study.

Whole plants and various weed parts (leaves, flowers, buds and fruits) were captured on camera between April and September in eastern Croatia. The plants were photographed in different habitats including wheat field, construction sites, parking lots, road edges, along railways, edges of uncultivated fields, wastelands. In total, 94 images of seven plants species were utilized. For *Calystegia sepium* L., 16 photos were used; for *Papaver rhoeas* L., 18 photos; for *Anagallis arvensis* L., 3 photos; for *Ambrosia artemisiifolia* L., 19 photos; for *Prunella vulgaris* L. plant, 4 photos; for *Convolvulus arvensis* L., 24 photos; and for *Xanthium strumarium* L., 10 photos. If multiple plants of one species was present, different individuals were photographed. The correct identification of plants was confirmed using dichotomous key and expert in weed science.

All images were captured between using a Xiaomi Redmi Note 10S smartphone, and all plant identification applications were downloaded into an Apple iPhone 13 smartphone from the App Store. Each app's accuracy was assessed as part of the evaluation. The topic of potential applications is covered, and suggestions for users are made. All data was processed using Microsoft Excel program.

4. Results

4.1. PlantNet

PlantNet is a citizen scientific initiative that uses machine learning to automatically identify plants from photos. This project, which was launched in 2009, was created by researchers (computer scientists and botanists) from a consortium that unites French research institutions (Institut de recherche pour le développement (IRD), Center de cooperation internationale en recherche agronomique pour le développement (CIRAD), Institut national de la recherche agronomique (INRA), Institut national de recherche en informatique et en automatique (INRIA), and the Tela Botanica network, with the support of the Agropolis (https://ec.europa.eu/). A smartphone application (and web version) that allows users to identify hundreds of plant species from user-taken photographs was released in 2013. There are several languages for it. In more than 180 countries around the world as of 2019, it had received over 10 million downloads (https://hal.science/). The app's major feature is a sorted list of the most probable species that includes an image or series of photographs of a certain plant. Additionally, the PlantNet search engine returns pictures of the data set that is closest to the requested observation, enabling interactive validation by the user and, at this time, allowing the identification of about 20 000 plant species. It is also important to note that the application is free to use and allows for unlimited photo uploads for identification. Figure 8 depicts the look of the PlanNet program, where you may instantly take a snapshot of the plant on the spot or upload it from your mobile device's photo collection.

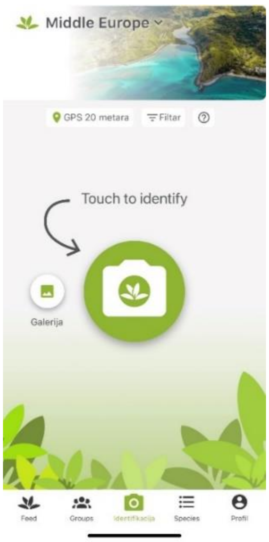

Figure 8. PlantNet identification application (Source: Bilić, D., 2023)

The display in the program once the desired photo has been loaded is shown in Figure 9 below. In this instance, a picture of the plant *Prunella vulgaris* L. was loaded as an example, and its plant was used to determine its identity.

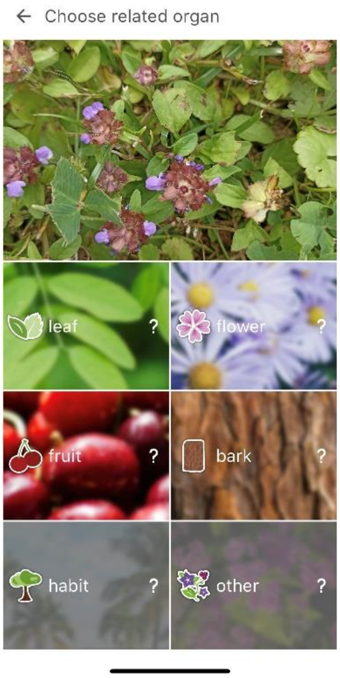

Figure 9. Uploading a photo to the PlantNet application (Source: Bilić, D., 2023)

The outcome of the PlantNet application's plant identification is shown in Figure 10. The plant *Prunella vulgaris* L. emerges as the first candidate for identification, indicating that the identification is accurate.

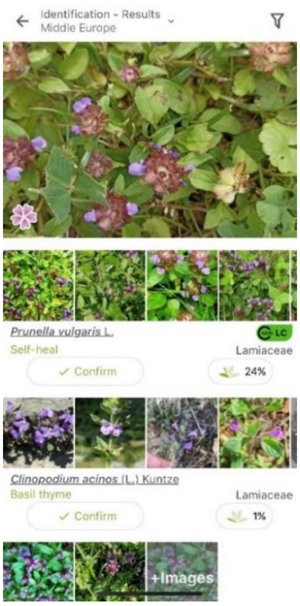

Figure 10. Presentation of the identification results of the plant *Prunella vulgaris* L. (Source: Bilić, D., 2023)

4.2. Blossom

Blossom is a tool you may use to take care of your plants. The app helps to identify plants based on images and furthermore diagnoses plant illnesses in addition to providing information about plants and care advice. In its database, Blossom has slightly more than 12 000 plants. After being downloaded to the smartphone, the app is free for three days before it must be purchased depending on the package. It is accessible on Google Play and the App Store. According to https://blossomplant.com/, the pricing range for monthly packages is 4.38 – 11.01 € and for yearly packages, 9.99 – 44.46 €. Figure 11 depicts the start of the application's use, where you may choose the options you require. To identify the required plant for the purposes of this article, the Identifying plants option was used. Caretaking advices, disease diagnosis, watering reminders, gardening tips, and other choices are also available.

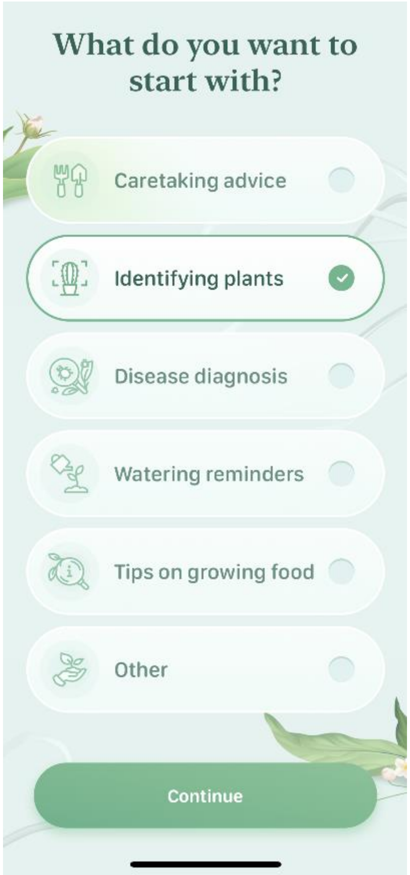

Figure 11. Selecting the Identify plants option in the Blossom application (Source: Bilić, D., 2023)

Two options - Search by name and Snap to identify, that were chosen for the work's aims are shown in Figure 12 as the next step in the plant identification procedure.

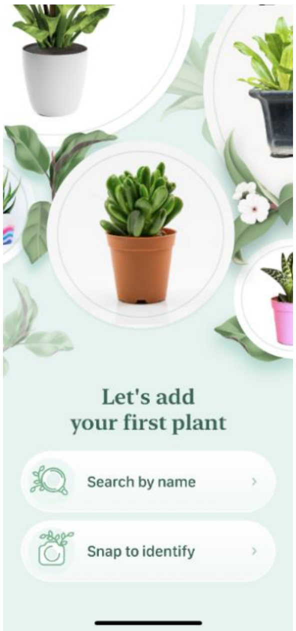

Figure 12. Selecting the Snap to identify option in the Blossom application (Source: Bilić, D., 2023)

The plant *Anagallis arvensis* L. was selected as an illustration of the outcomes for this application and is depicted in Figure 13. The identification is accurate since the result is the best match, or the plant *Anagallis arvensis* L. as the first option.

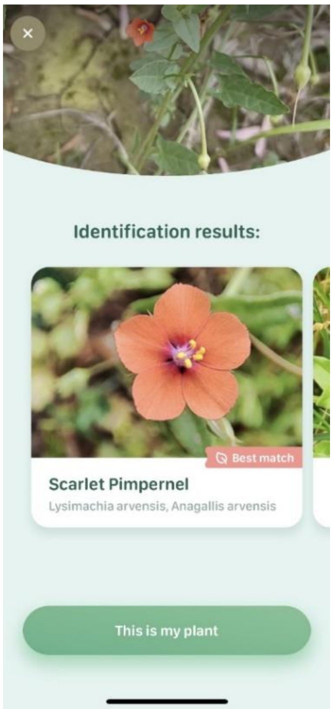

Figure 13. Presentation of the results of the identification of the plant *Anagallis arvensis* L. (Source: Bilić, D., 2023)

4.3. PlantIn

PlantIn is a program for identifying plants that has a database of around 16 000 different plant species (https://myplantin.com/). The program makes use of machine learning and artificial intelligence to identify plants in various lighting, development stages, and environmental settings. PlantIn also offers users a vast store of data on every identified plant species, including in-depth descriptions, ecological preferences, growth patterns, and historical relevance, going beyond simple identification. PlantIn's potential also extends to the agricultural and landscaping industries since it assists growers and gardeners in making the best decisions about plant selection and crop management. The software is available for download from the software Store and Google Play. The first three days of use are free, after which it costs between 2.39 € and 90.25 € depending on the weekly, monthly, or yearly package. Figure 14 displays the PlantIn application's first user interface, where the camera icon is selected to shoot or submit images for identification.

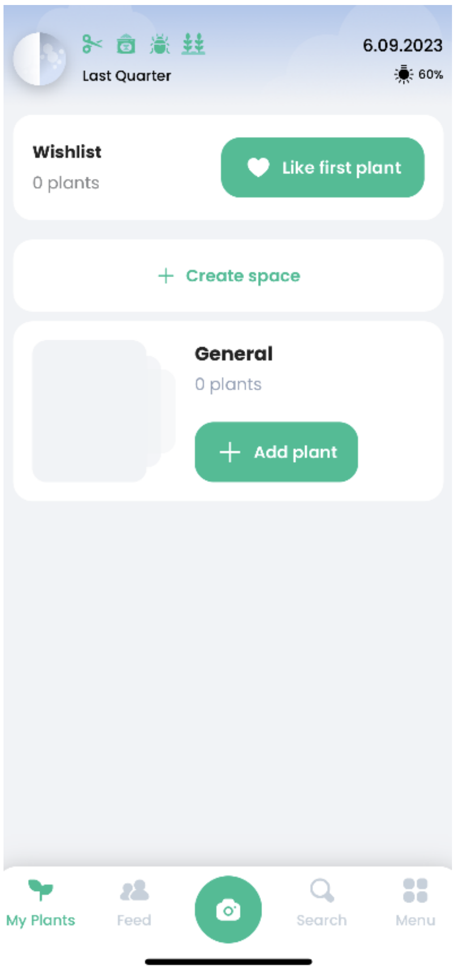

Figure 14. Layout of the PlantIn application interface (Source: Bilić, D., 2023)

The Figure 15 below is a representation of a PlantIn application identification utilizing the plant *Calystegia sepium* L.

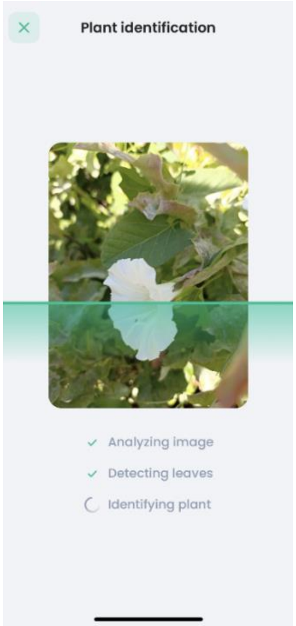

Figure 15. Uploading a photo of *Calystegia sepium* L. to the PlantIn application (Source: Bilić, D., 2023)

The identification outcome of the PlantIn application is displayed in Figure 16 below. Unfortunately, the application misidentified the plant that was provided, *Calystegia sepium* L., and instead recognized *Convolvulus cneorum* L. based only on the photo.

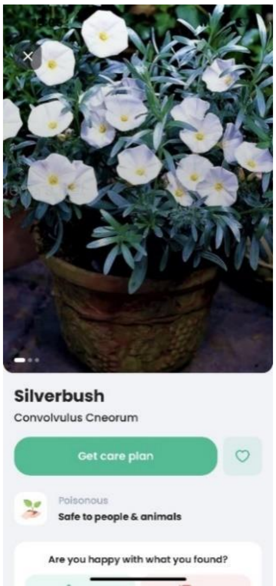

Figure 16. The identification result of the PlantIn application is *Convolvulus cneorum* L. (Source: Bilić, D., 2023)

4.4. Plantum

The pinnacle of plant identification apps, Plantum, is a prime example of how contemporary technology and biodiversity preservation are intertwined. Urbanization and climate change are posing increasing risks to ecosystems and the world's flora, making it more important than ever to have reliable and practical techniques for identifying plants. Utilizing machine learning and image recognition techniques, Plantum solves this problem by enabling users to correctly identify plant species from a single shot. Its extensive database, which is regularly updated and improved, includes many different plant taxa. By supplying users with extra details on plant traits, habitat preferences, and conservation status, Plantum goes above and beyond conventional field guides and promotes a greater appreciation for plant variety and environmental awareness. As evidence of its influence, Plantum supports a wide range of users in their attempts to record, comprehend, and save the world's botanical history, from amateur botanists and horticulture lovers to ecological experts and environmentalists. Plantum is an innovative instrument that has significant implications at a time of rising environmental consciousness and technology advancement.

According to the information on its website, the program (https://myplantum.com/) boasts a database of more than 15 000 plants with 98% accuracy in plant identification, 20 million users, and is available in slightly more than 135 countries. Mobile users may get the program from Google Play and the App Store. It should be mentioned that beyond the initial three days of free usage, the program may need payment based on the amount of time used and the features offered. Weekly packages cost between 5.31 € and 7.70 €, while monthly plans cost between 2.12 € and 21.90 €. Annual subscription prices range from 6.37 € to 33.18 €.

Figure 17 depicts the Plantum application's home page where user can select the Identify option to identify the plant before uploading or taking a shot, and then click the camera button.

In this case, the plant *Papaver rhoeas* L. was picked for plant identification based on a photo taken with the Plantum app, as shown in Figure 18.

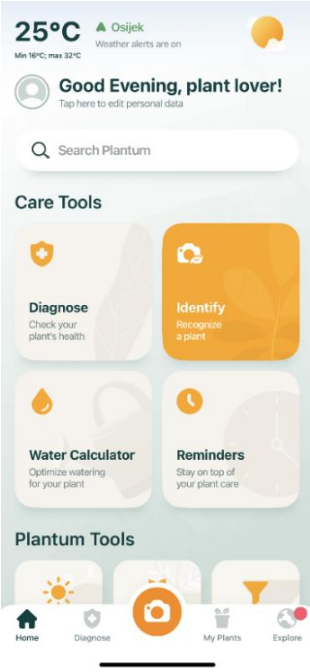

Figure 17. Selecting the Identify option in the Plantum application (Source: Bilić, D., 2023)

Figure 18. Loading a photo of the plant *Papaver rhoeas* L. (Source: Bilić, D., 2023)

The identification results are then displayed, as seen in Figure 19. The plant *Papaver rhoeas* L. was identified as the first choice, i.e. the best match, which matches the selected photo of the plant, and the identification result is correct.

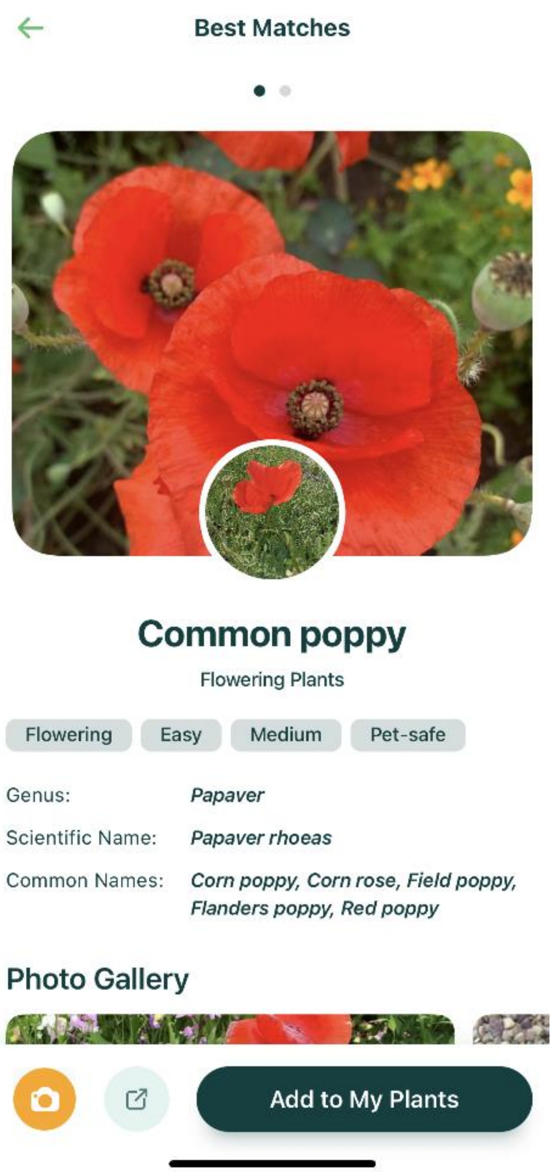

Figure 19. The result of the identification of the plant *Papaver rhoeas* L. in the Plantum application (Source: Bilić, D., 2023)

4.5. PlantMe

PlantMe is the final in a series of chosen plant identification applications. PlantMe is an innovative software that, like previous applications, employs powerful machine learning algorithms, picture recognition technology, and a massive database of plant species to give users with a smooth and accurate approach to identify diverse flora specimens. Its simple interface and real-time identification capabilities enable both eager enthusiasts and seasoned experts to investigate, identify, and learn about the plants in their surroundings. PlantMe's enormous collection of rich plant profiles, which includes information on growth patterns, habitat, care instructions, and even medicinal applications, lifts it beyond a basic identification tool, transforming it into an amazing instructional tool. The software supports the collection of crucial data for ecological studies and biodiversity monitoring by allowing users to reliably identify and categorize plant species in their natural environments. PlantMe's capability can help researchers expedite fieldwork and add to our understanding of plant distributions, adaptations, and reactions to environmental change, assisting in the conservation of fragile ecosystems and endangered species. The PlantMe app may be downloaded to any mobile device via Google Play or the App Store for a three-day free trial period, after which it can be used for a fee based on the chosen weekly, monthly, or annual plan. The costs of the packages range from 3.32 to 92.90 € (https://apps.apple.com/). Figure 20 depicts the PlantMe application's original configuration. In the center of the screen, the plant identification and recognition symbol is selected.

Figure 20. Selecting the plant identification icon in the PlantMe application (Source: Bilić, D., 2023)

A photo of the plant to be identified is also chosen. The plant *Ambrosia aremisiifolia* L. was chosen for this example, and the photo identification result is displayed in Figure 21. In this example, the PlantMe tool correctly identified the plant *Ambrosia artemisiifolia* L. as the first and only option.

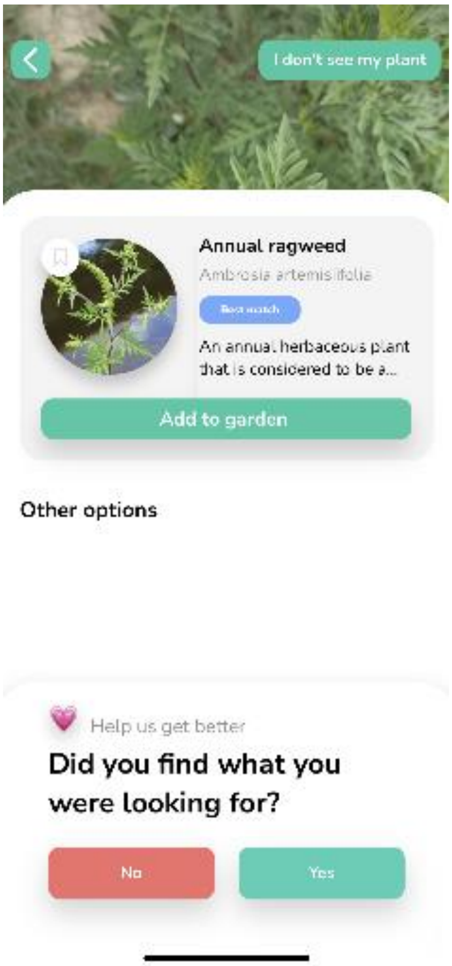

Figure 21. Presentation of the results of the identification of the plant *Ambrosia artemisiifolia* L. (Source: Bilić, D., 2023)

4.6. Identification of *Calystegia sepium* L.

In the case of *Calystegia sepium* L., 16 images were utilized to identify the plant using the PlantNet mobile application. The PlantNet application recognized the plant *Calystegia sepium* L. as the first choice in 15 of the 16 photographs, and as the second choice once (Figure 22). This results in a first choice percentage of 93.75% and a second choice percentage of 6.25%.

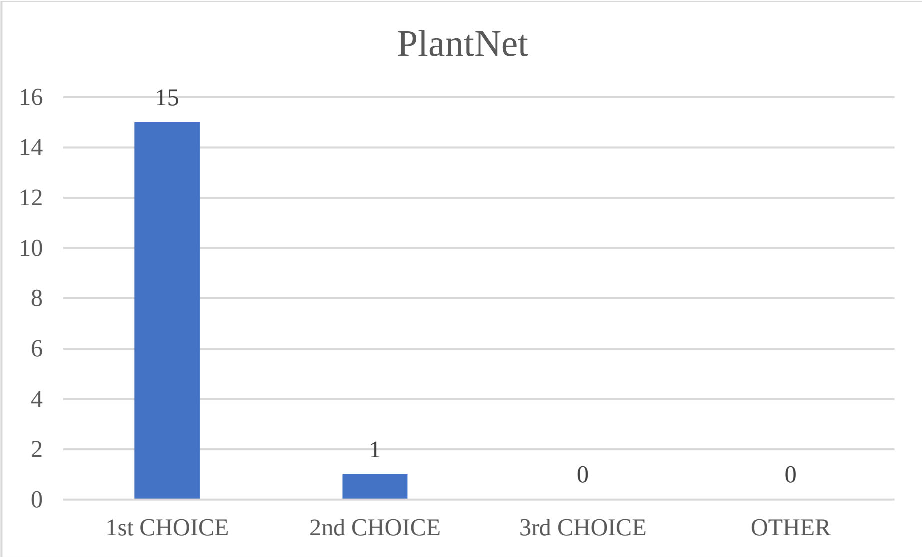

Figure 22. Results of the *Calystegia sepium* L. plant identification using the PlantNet application

Blossom, the second plant identification application, recognized *Calystegia sepium* L. as the top pick in 12 photographs, whereas the program did not recognize the same plant at all in the remaining four photos (Figure 23). As a result of recognition on those 4 photographs, the application identified the plant *Ipomoea purpurea* L.

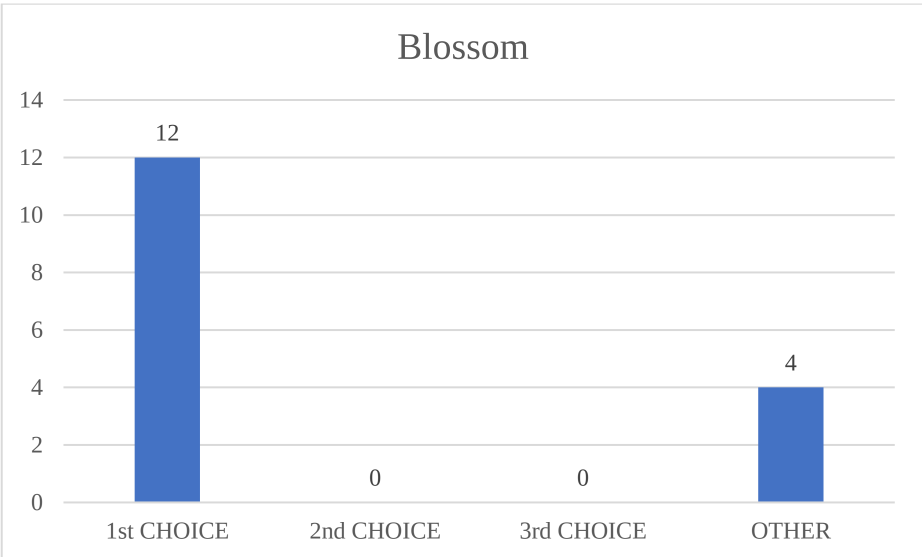

Figure 23. Results of the *Calystegia sepium* L. plant identification using the Blossom application

Figure 24 depicts how well PlantIn, the third plant identification application, identified the plant *Calystegia sepium* L. Only two photographs from the first were identified, while the remaining 14 photos were identified by the application as *Conovolvulus cneorum* L. and *Conovolvulus arvensis* L.

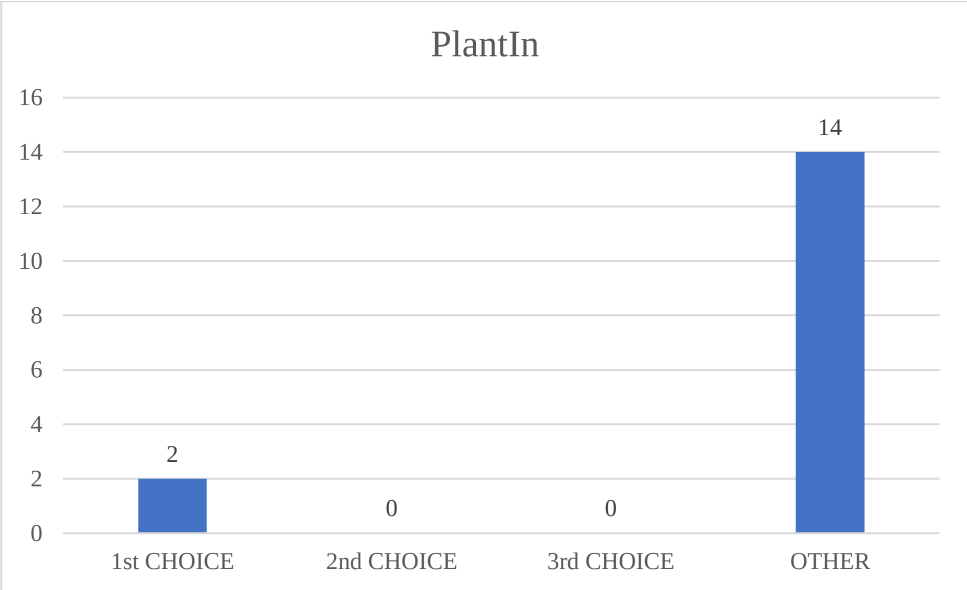

Figure 24. Results of the identification of the *Calystegia sepium* L. plant using the PlantIn application

The following Plantum application chose the plant *Calystegia sepium* L. as the top choice out of all 16 images, indicating that the identification rate was 100%, as shown in Figure 25.

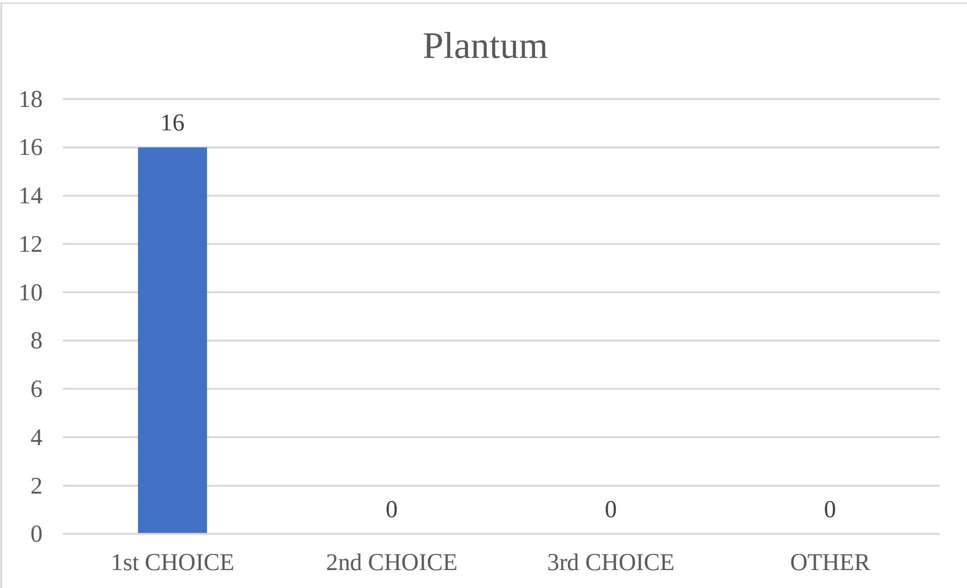

Figure 25. Results of the identification of the *Calystegia sepium* L. plant using the Plantum application

The last selected identification application PlantMe identified the plant *Calystegia sepium* L. as the first choice in 10 photos, which gives a percentage of 62.5% of the total number (Figure 26). In the recognition results, the app identified the same plant as the second choice in three photos, which is 18.75%, while as the third choice, the plant was identified in one photo. The application did not identify the plant *Calystegia sepium* L. as a possible result at all in the two photos, but instead identified it as *Ipomoea purpurea* L. and *Bromus secalinus* L.

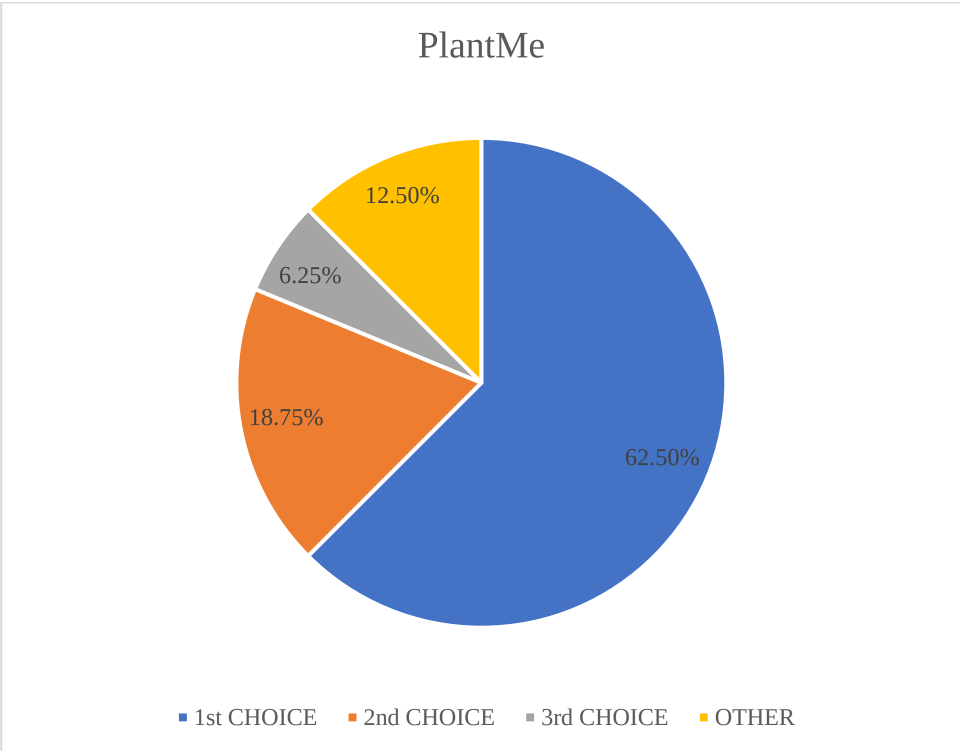

Figure 26. Results of the identification of the *Calystegia sepium* L. plant using the PlantMe application

4.7. Identification of *Papaver rhoeas* L.

The plant *Papaver rhoeas* L. was identified in 18 images, hence the PlantNet application recognized that plant as the first choice in 17 photos, whereas the same plant was recognized as the second choice in just one photo, as shown in Figure 27.

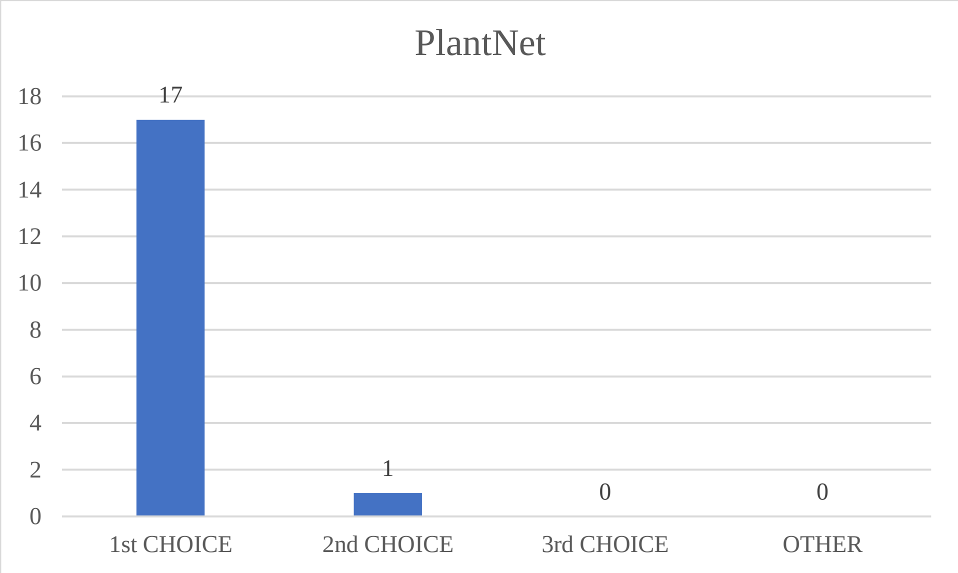

Figure 27. Results of the identification of the plant *Papaver rhoeas* L. using the PlantNet application

The percentages of identification of the *Papaver rhoeas* L. plant using the Blossom program are shown on Figure 28. The application recognized the plant as the first choice in eight photographs, or 44.44% of the total number of photos (18), while the plant *Papaver rhoeas* L. was not identified at all in the remaining 10 photos (55.56%). It was identified as *Ranunculus asiaticus* L. on three photos, *Eschscholzia Californica* L. on four, and *Papaver somniferum* L., *Centaurea scabiosa* L., and *Leucanthemum vulgare* L. on one of each.

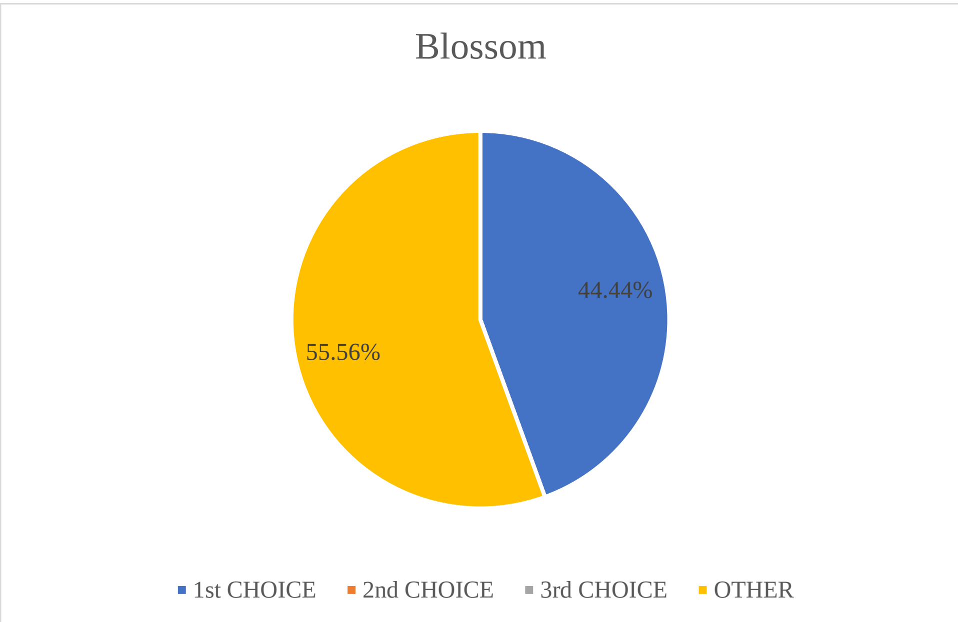

Figure 28. Results of the identification of the plant *Papaver rhoeas* L. using the Blossom application

The PlantIn and Plantum programs correctly identified the *Papaver rhoeas* L. plant in all 18 photographs, indicating that they were 100% accurate.

Figure 29 depicts the percentage of photos that dentified the plant of *Papaver rhoeas* L. using the PlantMe app. The application identified *Papaver rhoeas* L. as the top choice on 77.78% of the pictures, or 14 photos, and as the second choice on the remaining four photos (22.22%).

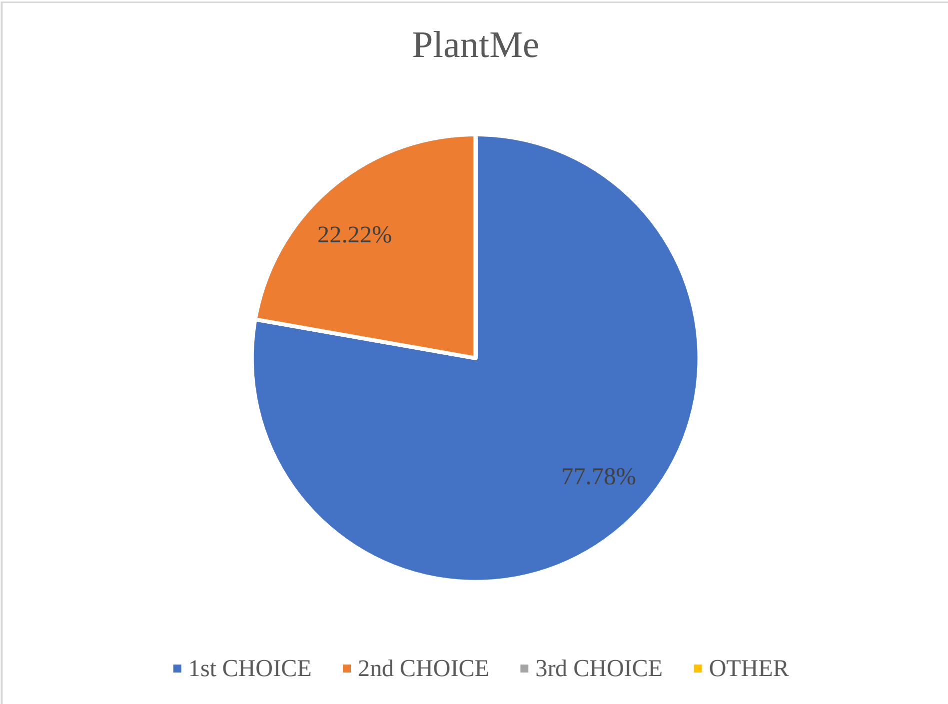

Figure 29. Results of the identification of the plant *Papaver rhoeas* L. using the PlantMe application

4.8. Identification of *Anagallis arvensis* L.

PlantNet, Blossom, Plantum, and PlantMe identified the plant *Anagallis arvensis* L. as the first choice in all three photos, whereas the PlantIn application did not recognize the plant *Anagallis arvensis* L. in any of the photos, nor did it output any identification result that is visible on Figure 30.

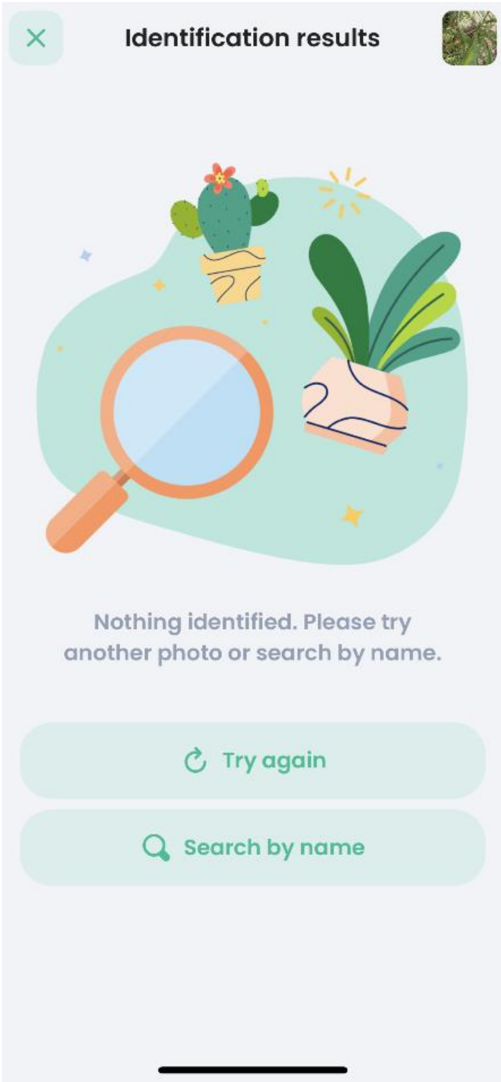

Figure 30. Results of the identification of the plant *Anagallis arvensis* L. using the PlantIn application (Source: Bilić, D., 2023)

4.9. Identification of *Ambrosia artemiisifolia* L.

The plant *Ambrosia artemiisifolia* L. was identified using 19 photographs. In this scenario, the majority of the plant identification applications (PlantNet, PlantIn, Plantum, and PlantMe) correctly identified the *Ambrosia artemiisifolia* L. plant and chose it as the first choice in all 19 photographs. As shown in Figure 31, only the Blossom application identified the plant *Ambrosia artemiisifolia* L. as the first choice in 57.89% of the photos, or 11 of them, while for 42.11%, or eight photos, it identified it as other plants such as *Solidago canadensis* L., *Cosmos sulphureus* L., *Cosmos bipinnatus* L., and *Eschscholzia californica* L.

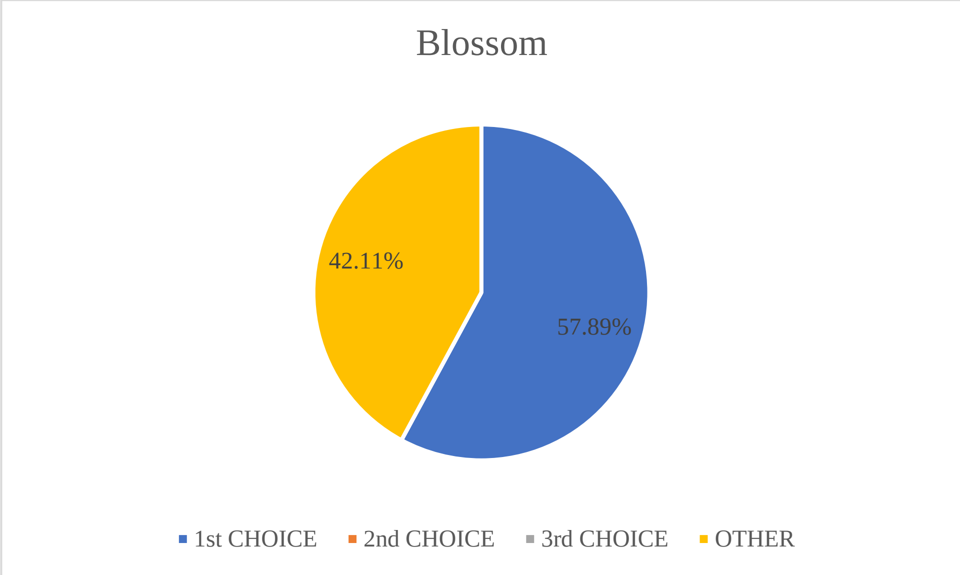

Figure 31. Results of the identification of the plant *Ambrosia aremisiifolia* L. using the Blossom application

4.10. Identification of *Prunella vulgaris* L.

The PlantNet, PlantIn, and Plantum mobile programs correctly identified all 4 photographs as the first choice for plant *Prunella vulgaris* L. The Blossom application made a half-hearted choice, as shown in Figure 32, by identifying *Prunella vulgaris* L. as the first choice in two photographs but not in the other two, identifying the plants as *Glechoma hederacea* L. and *Ajuga reptans* L. instead.

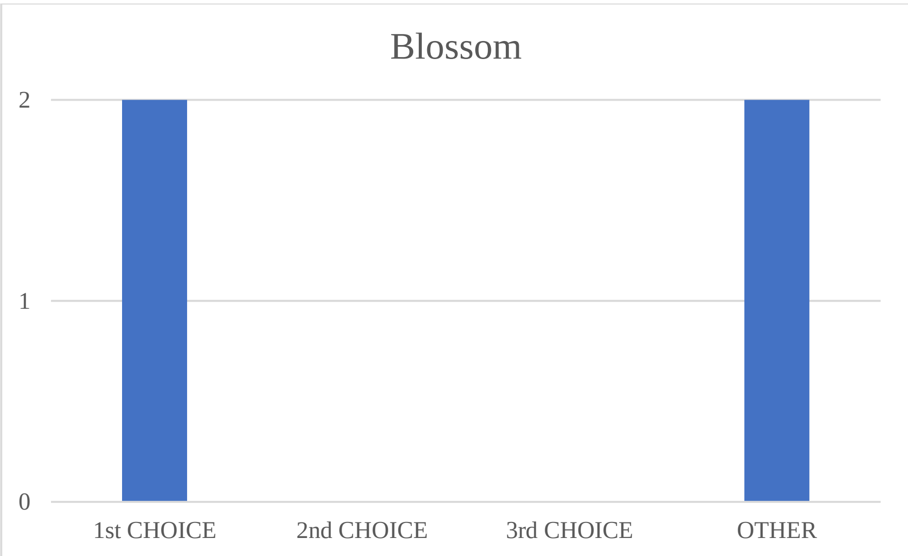

Figure 32. Results of the identification of the *Prunella vulgaris* L. plant using the Blossom application

The PlantMe application also detected the plant as *Glechoma hederacea* L., but only in one photo, while in the remaining three, it recognized *Prunella vulgaris* L. as the top pick, giving a percentage ratio of 25% to 75%, as shown in Figure 33.

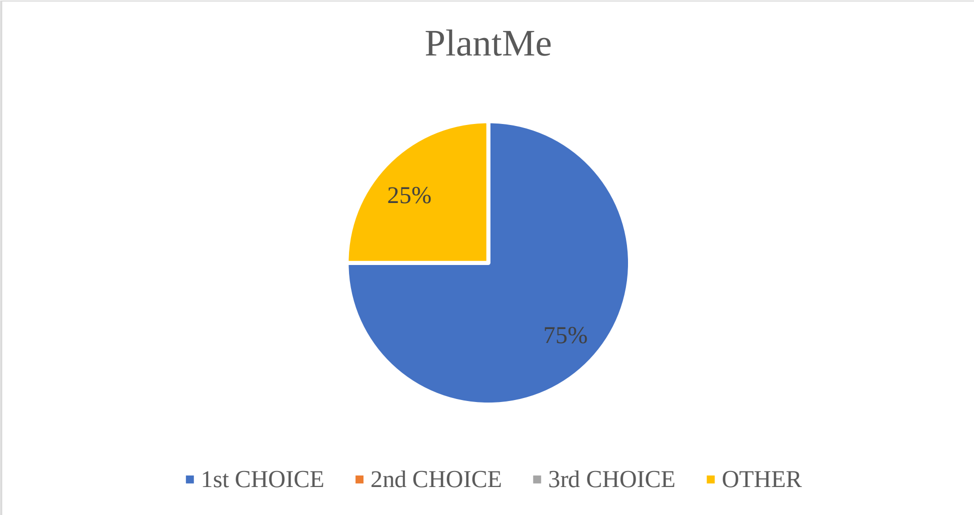

Figure 33. Results of the identification of the *Prunella vulgaris* L. plant using the PlantMe application

4.11. Identification of *Convolvulus arvensis* L.

Convolvulus arvensis L. was identified using 24 photos. According to PlantNet application (Figure 34), the plant *Convolvulus arvensis* L. was recognized as the first choice in 23 photographs, while it was placed as the third choice in one shot.

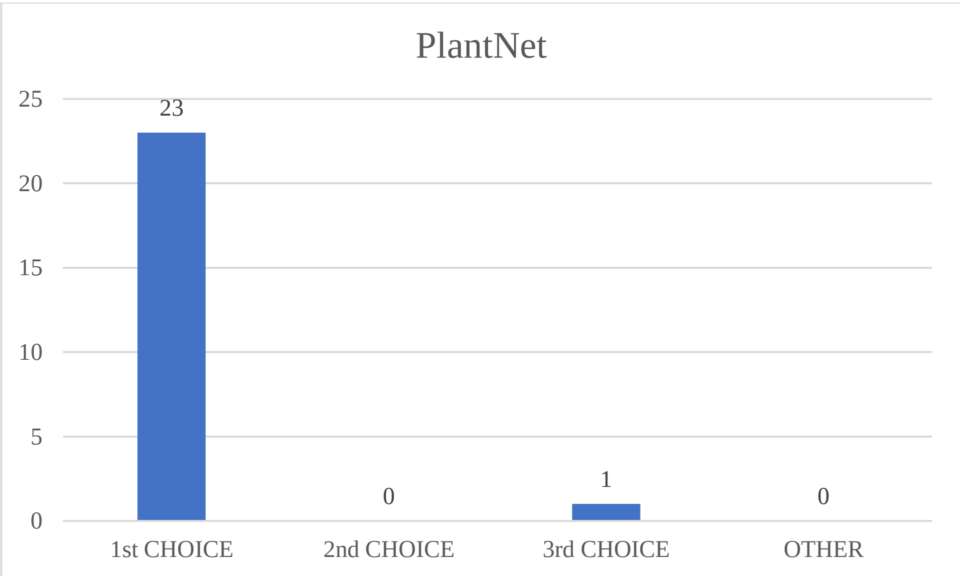

Figure 34. Results of the identification of the *Convolvulus arvensis* L. plant using the PlanNet application

Blossom, whose results are shown in Figure 35, identified the plant *Convolvulus arvensis* L. as the first choice in 66.67% of the photos (16), two of them, i.e. 8.33%, as the second choice, and 25% of the photos (six) did not recognize the plant *Convolvulus arvensis* L. as a result, but other plants such as *Petunia* spp. and *Ipomoea purpurea* L.

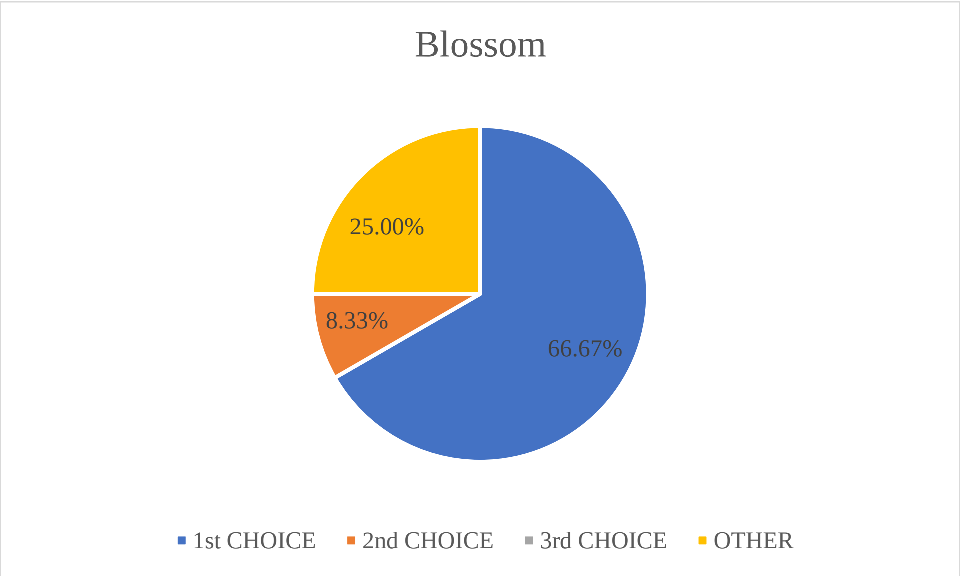

Figure 35. Results of the identification of the *Convolvulus arvensis* L. plant using the Blossom application

As demonstrated in Figure 36, the PlantIn application failed to identify the plant *Convolvulus arvensis* L. in a far greater percentage of 79.17% (19 photographs) or provide any other plant as an identification result, while identifying five photos (20.83%) as the first choice.

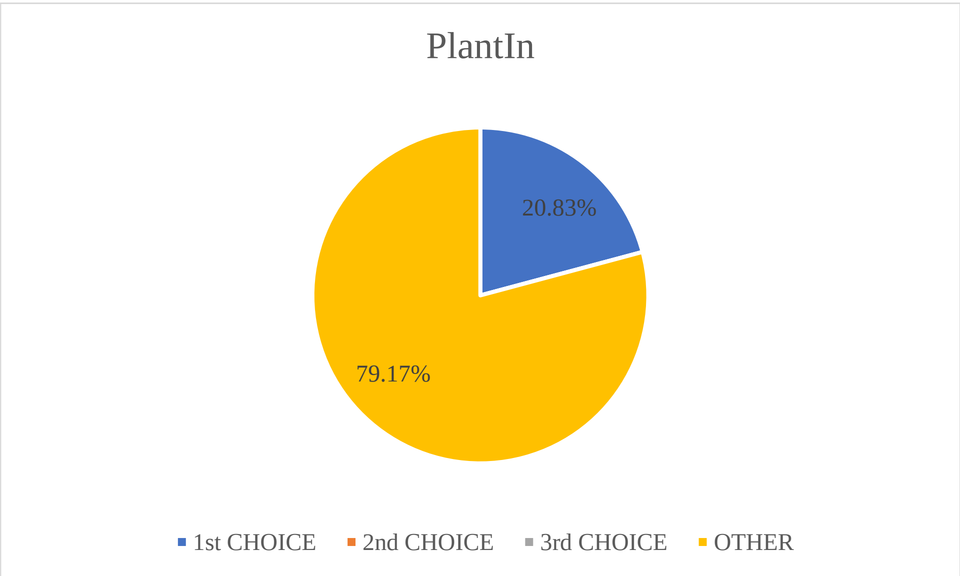

Figure 36. Results of the identification of the *Convolvulus arvensis* L. plant using the PlanIn application

The results of the Plantum application for the plant *Convolvulus arvensis* L. are shown in Figure 37. It recognized the *Convolvulus arvensis* L. as the top choice in 20 photographs (83.33%), the second choice in two photos (8.33%), the third choice in one (4.17%), and offered the plant *Calystegia sepium* L. in one photo (4.17%).

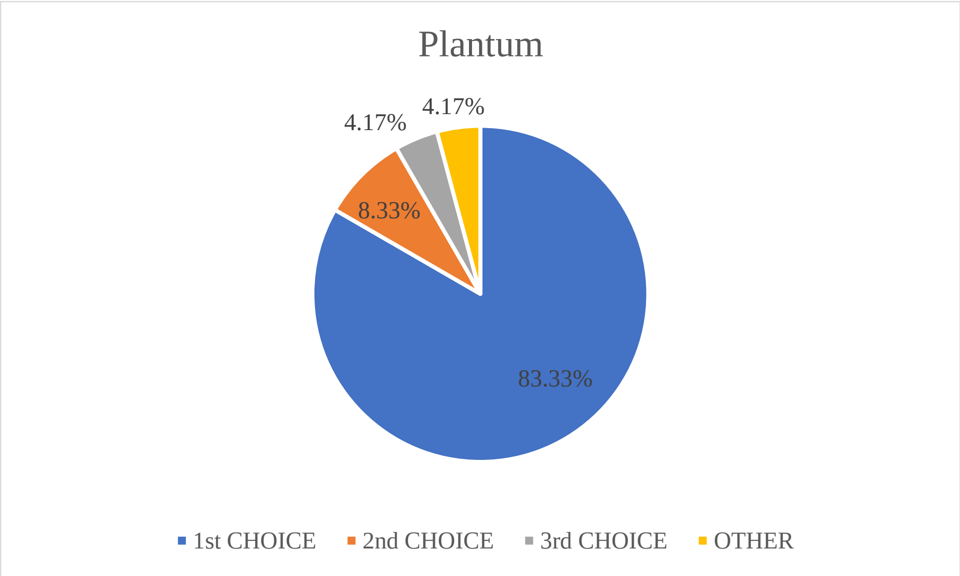

Figure 37. Results of the identification of the *Convolvulus arvensis* L. plant using the Planum application

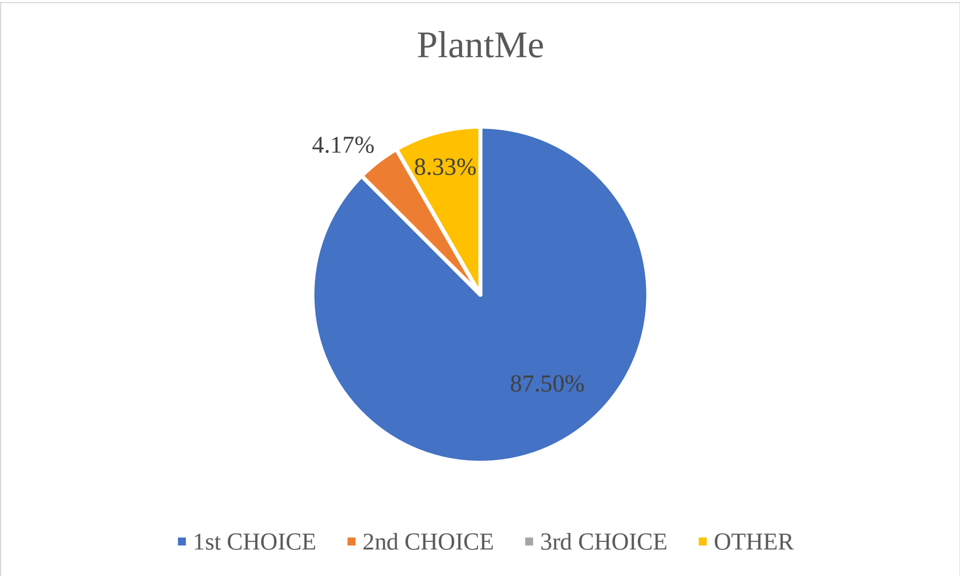

Figure 38. Results of the identification of the *Convolvulus arvensis* L. plant using the PlanMe application

Figure 38 depicts the results of recognizing the plant *Convolvulus arvensis* L. using the PlantMe program. *Convolvulus arvensis* L. was classified as the first choice in 87.5% of the photographs (21), and as the second choice in one photo (4.17%). It was not identified in two images (8.33%), however the plants *Cynanchum ovalifolium* L. and *Calystegia sepium* L. were identified in one shot, while *Ipomoea purpurea* L. and *Cercis canadensis* L. were identified in the other.

4.12. Identification of *Xanthium strumarium* L.

Using mobile applications, 10 images were utilized to identify the plant *Xanthium strumarium* L. Figure 39 depicts the PlantNet application's identification findings for the plant *Xanthium strumarium* L. This plant was identified as the first choice in nine photographs (90%) and the second choice in one photo (10%).

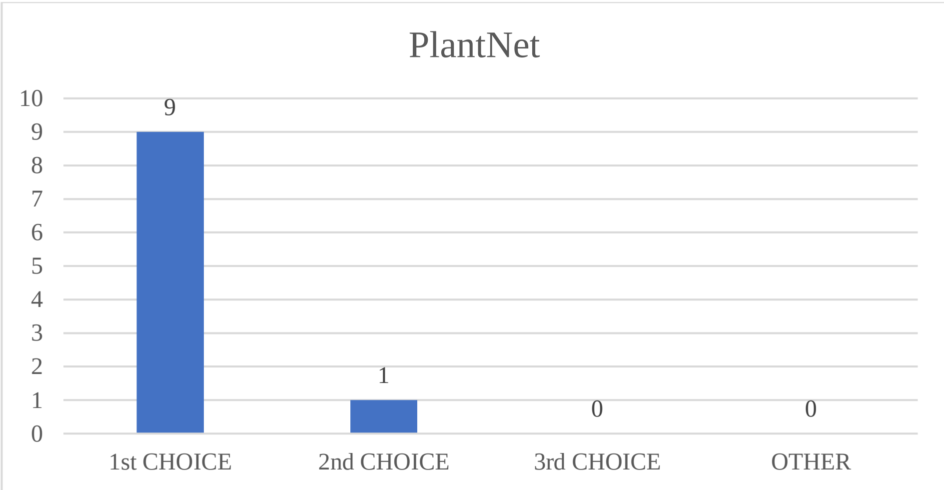

Figure 39. Results of identification of the plant *Xanthium strumarium* L. with the PlantNet application

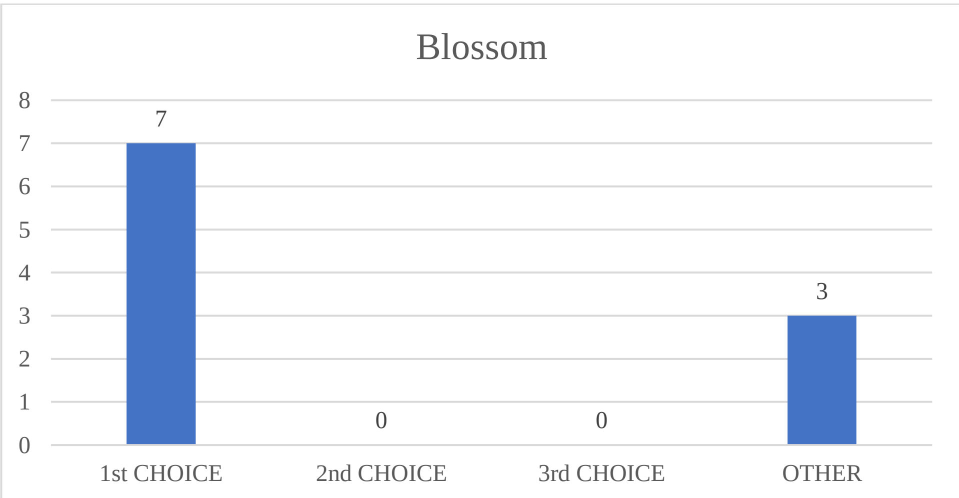

Figure 40. Results of identification of the plant *Xanthium strumarium* L. with the Blossom application

The Blossom application identified the plant *Xanthium strumarium* L. as the first choice in seven photos (70%) and offered other plants such as *Chenopodium quinoa* L., *Vitis vinifera* L., and *Populus nigra Italica* L. in three photos (30%) (Figure 40).

The PlantIn program identified the plant *Xanthium strumarium* L. as the first choice in nine photographs (90%), while in one photo (10%) it identified the plants *Persicaria orientalis* L. and *Reynoutria japonica* L. as identification results, as shown in Figure 41.

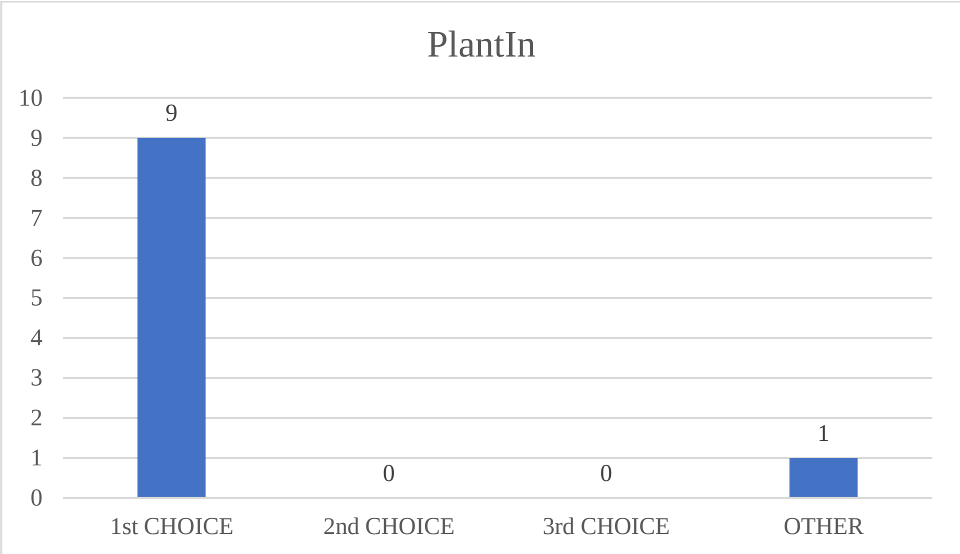

Figure 41. Results of identification of the plant *Xanthium strumarium* L. with the PlantIn application

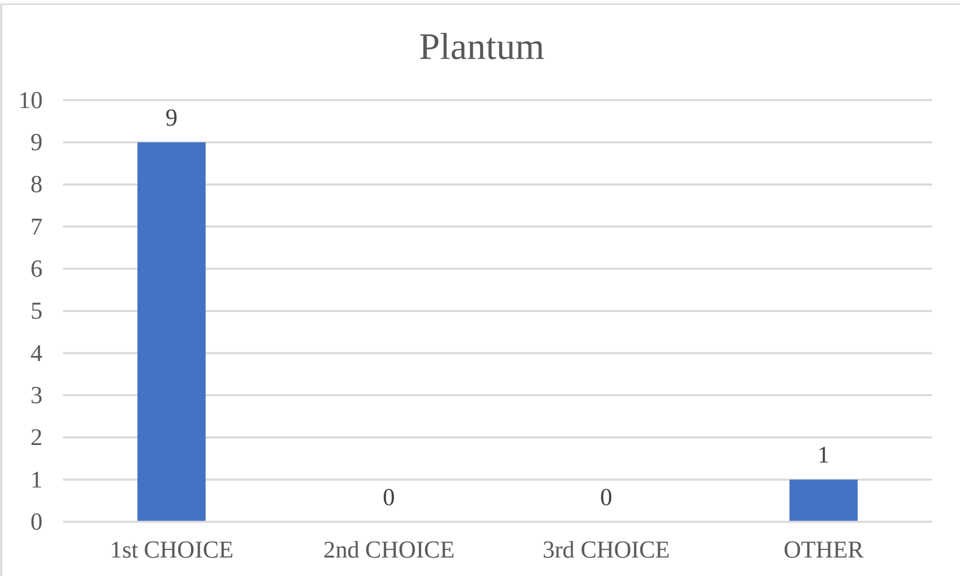

Figure 42. Results of identification of the plant *Xanthium strumarium* L. with the Plantum application

The Plantum application, like its predecessor, identified the plant *Xanthium strumarium* L. as the first choice in nine images (90%), whereas the identification results of the plants *Holcus lanatus* L. and *Triticum aestivum* L. were given in one photo (10 %) (Figure 42).

Figure 43 depicts the findings of the most recent PlantMe plant identification application in the example of *Xanthium strumarium* L. PlantMe correctly identified the plant *Xanthium strumarium* L. in one photo (10%) but not in the remaining nine (90%). The plants recognized in these photographs by the application are: *Brassica oleracea* L., *Abelmoschus esculentus* L., *Cucurbita pepo* L., *Helianthus annuus* L., *Articum minus* L., *Cynara cardunculus* L., *Glechoma hederacea* L., *Datura wrightii* L., *Reynoutria japonica* L., *Triticum aestivum* L., *Phalaris* sp., *Phleum* sp. *i Holcus mollis* L.

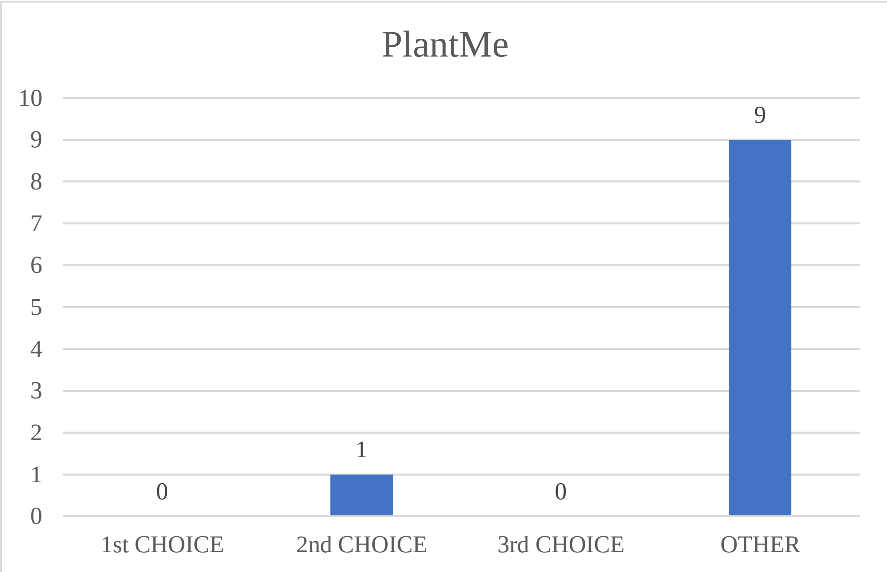

Figure 43. Results of identification of the plant *Xanthium strumarium* L. with the PlantMe application

4.13. Identification of the PlantNet application

The accuracy results of the PlantNet plant identification application are shown in Figure 44. The application recognized 90 of the total number of images of all seven plants (94) as the top option, for a rate of 95.74%. It recognized plants as the second choice in three photographs (3.19%) and one photo as the third choice (1.06% of the total number). Except for the seven plants detected in the study, the PlantNet tool failed to identify any additional plants in the photos.

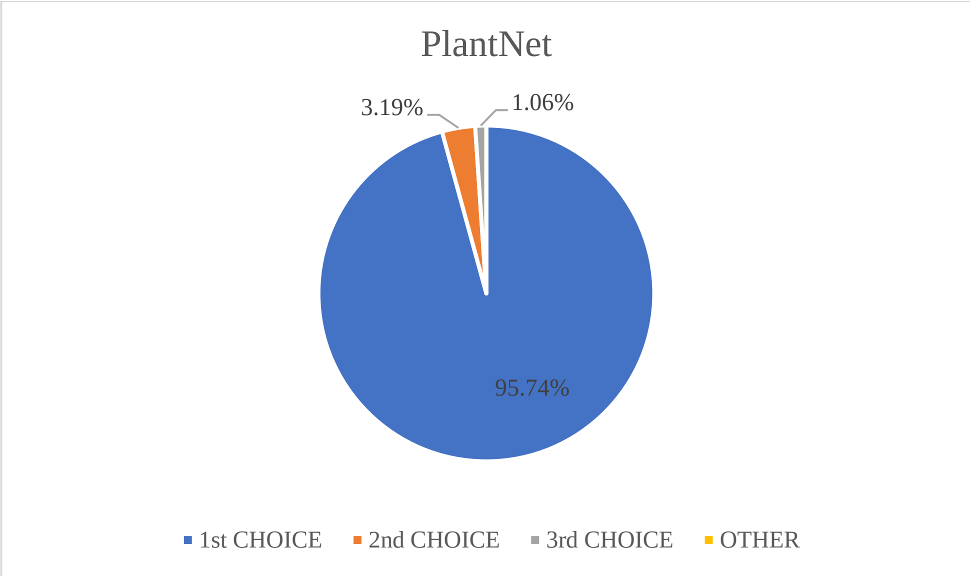

Figure 44. Accuracy of PlantNet application for identification of all seven plants

4.14. Identification of the Blossom application

Blossom, a plant identification app, recognized the same plants in 59 of the 94 photographs as the first choice (62.77%), while it recognized the same plants in two photos as the second choice (2.13%) (Figure 45). As a third option, the application did not recognize any of the observed plants, and as a result, it excluded not only the observed seven plants, but also some others in as many as 33 photographs (35.11%).

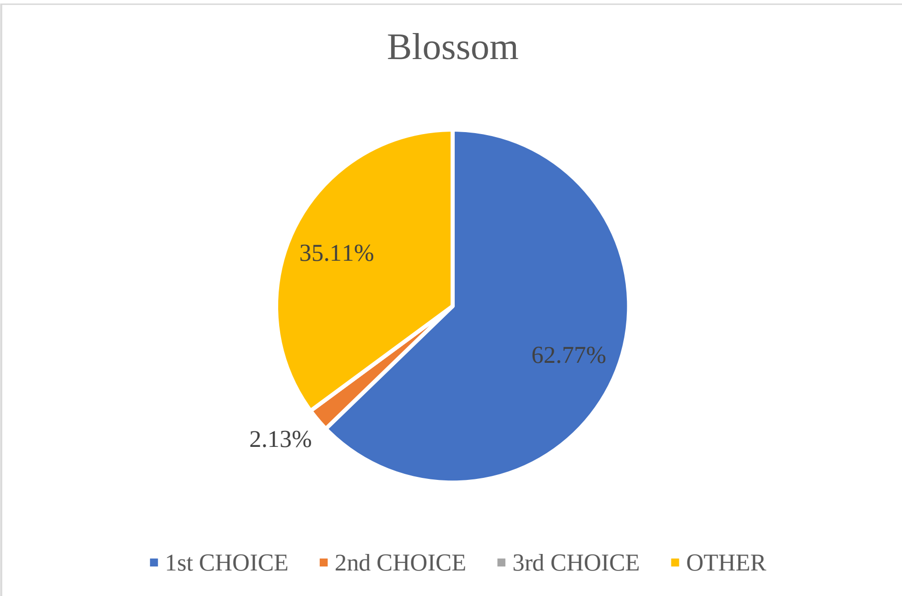

Figure 45. Accuracy of Blossom application for identification of all seven plants

4.15. Identification of the PlantIn application

The findings of the identification of seven observed plants using the PlantIn program are shown in Figure 46. PlantIn identified the observed plants as the first choice in 60.64% of the 57 images, with no results for the second and third choices. The PlantIn program did not detect a single observed plant in the remaining 37 photographs (39.36%), but did identify other plants as a result.

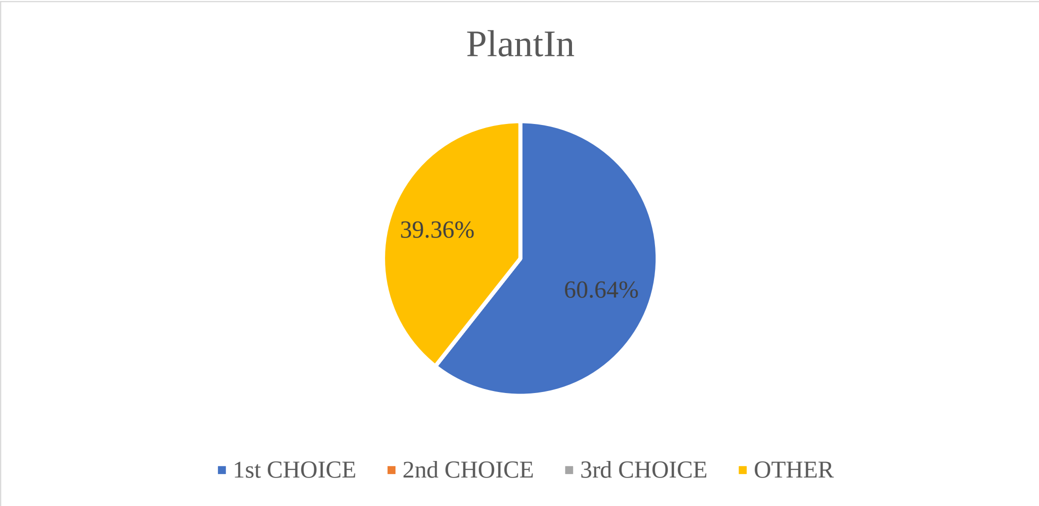

Figure 46. Accuracy of PlantIn application for identification of all seven plants

4.16. Identification of the Plantum application

Plant identification software with a percentage of 94.68%, Plantum chose 89 photographs as the first choice out of 94 photos of seven observed plants (Figure 47).

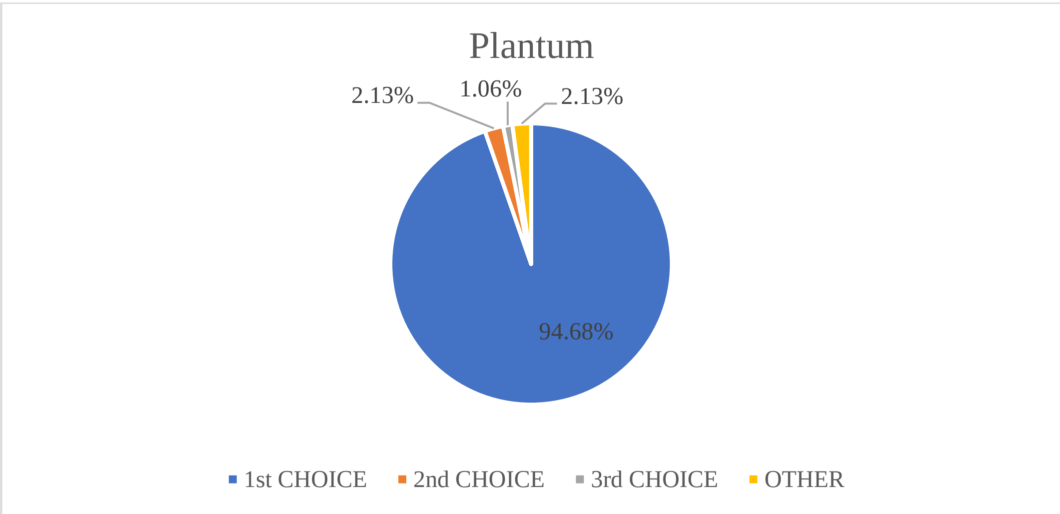

Figure 47. Accuracy of Plantum application for identification of all seven plants

The application identified the observed plants as the second choice in two photographs (2.13%), and as the third choice in one shot (1.06%). The Plantum program failed to identify the observed plants on 2.13% of the total number, or two images.

4.17. Identification of the PlantMe application

Figure 48 depicts the PlantMe plant identification application's results. The PlantMe application selected the observed plants as the first choice in 70 of the 94 used images of seven observed plants (74.47%). The observed plants were then identified as the second choice in 9 photographs (9.57%), and as the third choice in one photo (1.06%). PlantMe detected several other plants in 14 photos, which is 14.89%, but none of the seven observed in the study.

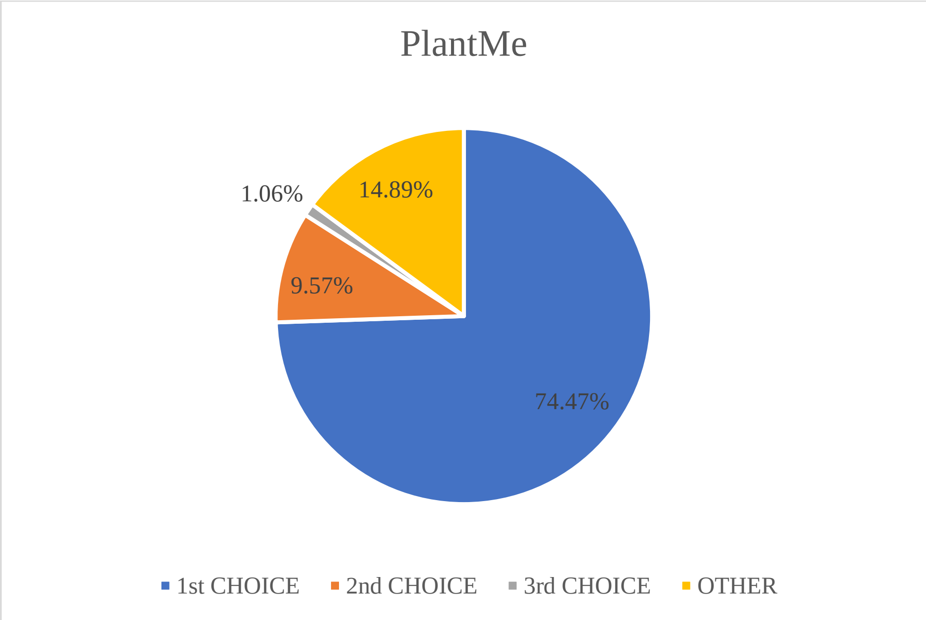

Figure 48. Accuracy of PlantMe application for identification of all seven plants

4.18. Comparison of accuracy results of all five applications

Figure 49 compares the accuracy of all five mobile applications for identifying sven different plants. The results are shown as a percentage of the best choice of identification across all 94 photos, i.e. the percentage of the identified observed plant's first pick. PlantNet has the greatest percentage (95.74%), followed by Plantum, which has a rate of 94.68%. The PlantMe program identified the observed plants as the first pick in 74.47% of the photographs, a 20% lower rate than the prior two applications. Blossom and PlantIn applications showed a substantially lower proportion of identification than other applications. The Blossom mobile app ranks fourth with 62.77%, while the PlantIn app ranks last with 60.64%.

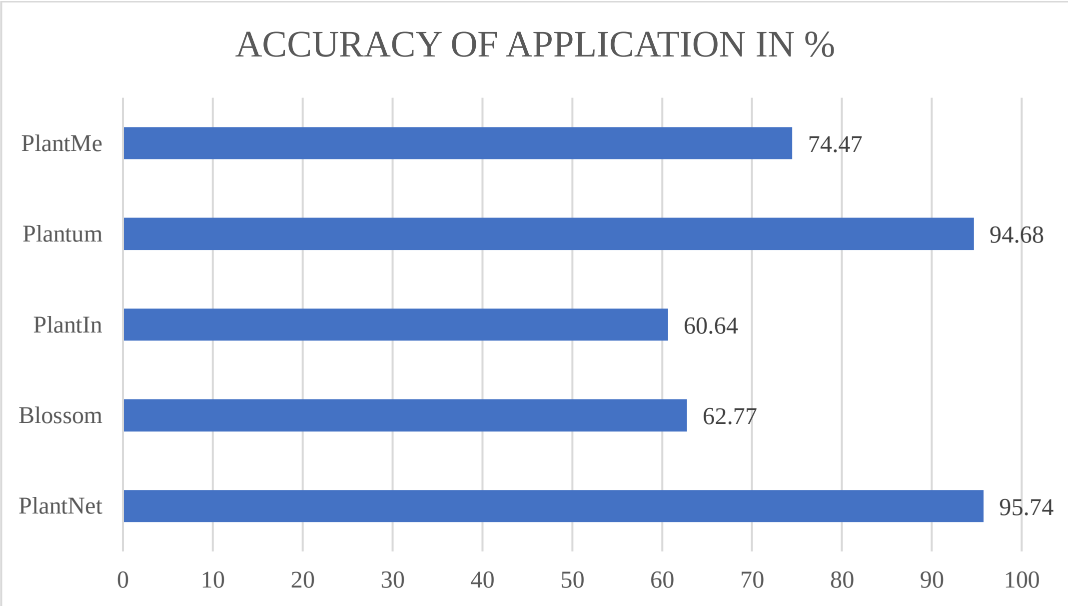

Figure 49. Comparison of the accuracy of all applications for the identification of all 7 plants

5. Discussion

The accuracy results of five mobile applications for the identification of seven seen plants based on 94 images collected in eastern Croatia are reported in this study. First, when comparing the accuracy of identification of the plant *Calystegia sepium* L. based on 16 photos, the Plantum application proved to be the best, with 100%, followed by PlantNet with 93.75%, and the PlantIn application, which recognized only 12.5% of the photos as *Calystegia sepium* L. When it comes to the following plant, *Papaver rhoeas* L., the best results are PlantIn and Plantum, which are both 100% accurate, while Blossom has the lowest accuracy score of 44.44%. The PlantIn application has a very poor result for identifying the plant *Anagallis arvensis* L. based on three photographs, as it did not recognize a single plant or show any results, whereas the other four applications all show 100% accuracy. In contrast to the previous application, the Blossom application has the lowest recognition rate of the *Ambrosia artemisiifolia* L. plant at 57.89 %, whereas the other four applications are all 100% based on 19 photos. Based on four images of the *Prunella vulgaris* L. plant, the PlantNet, PlantIn, and Plantum programs are 100% accurate, while PlantMe is 75% accurate, and the Blossom application is 50% accurate. The percentages of correct identification of the plant *Convolvulus arvensis* L. for 24 pictures varied greatly. The PlantNet application has the best accuracy (95.83%), followed by PlantMe (87.50%), and Plantum (83.33%). Blossom has an accuracy of 66.67% in this scenario, while PlantIn has an accuracy of only 20.83%. Ten photographs were utilized to identify the plant *Xanthium strumarium* L., and three apps (PlantNet, PlantIn, and Plantum) produced the same 90% accuracy result. In this situation, the Blossom program provides 70% accuracy, while the PlantMe application provides the lowest results, failing to identify *Xanthium strumarium* L. as the first choice in any shot. When the total and final accuracy results based on all 94 photographs of all plants are considered, PlantNet ranks first with 95.74%, followed by Plantum with 94.68%. The PlantMe application comes in third position with 74.47%. Blossom is ranked fourth with 62.77%, whereas PlantIn has the lowest performance with 60.64% and consequently ranks last. Given that the PlantNet program is the only one that is free to use and has the highest accuracy, it is easy to infer that it is the best choice for daily use and plant identification.

It is interesting to observe how the Plantum and PlantMe applications, when identifying *Xanthium strumarium* L., recognized the wheat (*Triticum aestivum* L.) surrounding it in the images because it was also photographed in a wheat field. Furthermore, when identifying

Calystegia sepium L., the Blossom, PlantIn and PlantMe applications recognized the plants *Convolvulus arvensis* L., *Convolvulus cneroum* L. and *Ipomoea purpurea* L. on the basis of images because they belong to the same family Convolvulaceae. Also, when identifying *Convolvulus arvensis* L., the Blossom, Plantum and PlantMe applications recognized the plants *Calystegia sepium* L. and *Ipomoea purpurea* L., which belong to the same family Convolvulaceae.

Other studies also reported various results concernig the identification of plants using mobile applications. For example, in Otter et al. (2021) study, when 17 species of toxic plants were discovered, the PlantNet application did not perform as well as in this work, with a recognition percentage of 47% on a sample of 69 images. Similarly, Hart et al. (2023) also examined five mobile plant identification programs, one of which being PlantNet. The accuracy findings (95%) from that study are almost identical to the results of this paper, based on 857 pictures to recognize 227 species of plants. In the investigation of Campbell et al. (2023), PlantNet likewise revealed to be the application with the best percentage of identification accuracy when recognizing herbaceous plants in 88.21% of cases, as it did here.

6. Conclusion

Weeds are well known for competing with agricultural crops for light, water, soil, and nutrients in order to grow and develop, consequently reducing crop yields. Weeds are also part of the urban habitat where they can have a harmful significance, but they can also have beneficial properties. Thus, weeds are present in lives and work, and it is critical that others understand and correctly identify them so that they may be dealt with or used. Plant identification systems based on machine learning algorithms and computer vision techniques for image recognition have been developed as technology has advanced, allowing users to obtain plant identification much more quickly. All the user has to do now is pull his mobile device out of his pocket, take a photo of the plant on the scene, and receive the result of plant identification and further information. This study demonstrated that the applications can accurately identify plants, with the Plantum and PlantNet applications achieving an accuracy of approximately 95%.

7. References

1. Barré, P., Stöver, B.C., Müller, K.F., Steinhage, V. (2017): LeafNet: A computer vision system for automatic plant species identification. Ecological Informatics, 40: 50-56.
2. Bilyk, Z.I., Shapovalov, Y.B., Shapovalov, V.B., Megalinska, A.P., Andruszkiewicz, F., Dołhańczuk-Śródka, A. (2020): Assessment of mobile phone applications feasibility on plant recognition: comparison with Google Lens AR-app, CEUR Workshop Proceedings, 2731: 61-78.
3. Bonnet, P., Joly, A., Goëau, H., Champ, J., Vignau, C., Molino, J-F., Barthélémy, D., Boujemaa, N. (2016): Plant identification: man vs. machine. Multimedia Tools and Applications, 75: 1647–1665.
4. Campbell, N., Peacock J., Bacon K.L. (2023): A repeatable scoring system for assessing Smartphone applications ability to identify herbaceous plants. PLOS ONE, 18(4): e0283386.
5. D'Antonio, C., Meyerson, L. (2002): Exotic Plant Species as Problems and Solutions in Ecological Restoration: A Synthesis, Restoration Ecology, 10: 703-713.
6. Fan, W., Fan, L., Peng, C., Zhang, Q., Wang, L., Li, L., Wang, J., Zhang, D., Peng, W., Wu, C. (2019): Traditional Uses, Botany, Phytochemistry, Pharmacology, Pharmacokinetics and Toxicology of *Xanthium strumarium* L.: A Review. Molecules, 24(2): 359.
7. Fischer, L.K., von der Lippe, M., Kowarik, I. (2013): Urban land use types contribute to grassland conservation: The example of Berlin. Urban Forestry & Urban Greening, 12(3): 263-272.
8. Forenbacher, S. (2001): Velebit i njegov biljni svijet. Školska knjiga, Zagreb.
9. Goëau, H., Bonnet, P., Joly, A., Bakić, V., Barbe, J., Yahiaoui, I., Selmi, S., Carré, J., Barthélémy, D., Boujemaa, N., Molino, J-F., Duché, G., Péronnet, A. (2013): Pl@ntNet mobile app, In Proceedings of the 21st ACM international conference on Multimedia, Association for Computing Machinery, New York, NY, USA, 423–424.
10. Grime, J.P. (2006): Plant strategies, vegetation processes, and ecosystem properties. John Wiley & Sons, New York, USA.
11. Hart, A.G., Bosley, H., Hooper, C., Perry, J., Sellors-Moore, J., Moore, O., Goodenough, A.E. (2023): Assessing the accuracy of free automated plant identification applications, People and Nature: 5, 929–937.

12. Hole, D.G., Perkins, A.J., Wilson, J.D., Alexander, I.H., Grice, P.V., Evans, A.D. (2005): Does organic farming benefit biodiversity? Biological Conservation, 122(1): 113-130.
13. Hope, D., Gries, C., Zhu, W., Fagan, W., Redman, C., Grimm, N., Nelson, A., Martin, C., Kinzig, A. (2003): Socioeconomics Drive Urban Plant Diversity. Proceedings of the National Academy of Sciences of the United States of America, 100: 8788-8792.
14. Knežević, M. (2006): Atlas korovne, ruderalne i travnjačke flore. Poljoprivredni fakultet u Osijeku, Osijek.
15. Kress, W.J., Garcia-Robledo, C., Soares, J.V.B., Jacobs, D., Wilson, K., Lopez, I.C., Belhumeur, P.N. (2018): Citizen Science and Climate Change: Mapping the Range Expansions of Native and Exotic Plants with the Mobile App Leafsnap. BioScience, 68(5): 348–358.
16. Lang, V., Šorgo, A. (2022): Added value of the Pla@ntNet smartphone application for the motivation and performance lolwer secondary school students in species identification, ICERI2022 Proceedings, pp. 4534-4540.
17. Leff, J.W., Bardgett, R.D., Wilkinson, A., Jackson, B.G., Pritchard, W.J., De Long, J. R., Oakley, S., Mason, K.E., Ostle, N.J., Johnson, D., Baggs, E.M., Fierer, N. (2018): Predicting the structure of soil communities from plant community taxonomy, phylogeny, and traits. The ISME journal, 12(7): 1794–1805.
18. Lundholm, J. (2009): Plant species diversity and environmental heterogeneity: Spatial scale and competing hypotheses. Journal of Vegetation Science, 20: 377-391.
19. Mäder, P., Boho, D., Rzanny, M., Seeland, M., Wittich, H. C., Deggelmann, A., Wäldchen, J. (2021): The Flora Incognita app – Interactive plant species identification. Methods in Ecology and Evolution, 12: 1335–1342.
20. Mangina, E., Burke, E., Matson, R., O'Briain, R., Caffrey, J.M., Saffari, M. (2022): Plant Species Detection Using Image Processing and Deep Learning: A Mobile-Based Application. In: Bochtis, D.D., Moshou, D.E., Vasileiadis, G., Balafoutis, A., Pardalos, P.M. (eds) Information and Communication Technologies for Agriculture—Theme II: Dana, Springer Optimization and Its Applications, vol 183. Springer, Cham.
21. Maretić, Z. (1986): Naše otrovne životinje i bilje. Stvarnost, Zagreb.
22. McDonnell, M.J., Hahs, A.K. (2008): The use of gradient analysis studies in advancing our understanding of the ecology of urbanizing landscapes: current status and future directions. Landscape Ecology, 23: 1143–1155.

23. Mendes, J., Pinho, T.M., Neves dos Santos, F., Sousa, J.J., Peres, E., Boaventura-Cunha, J., Cunha, M., Morais, R. (2020): Smartphone Applications Targeting Precision Agriculture Practices—A Systematic Review. Agronomy, 10(6): 855.
24. Otter, J., Mayer, S., Tomaszewski, C.A. (2021): Swipe Right: a Comparison of Accuracy of Plant Identification Apps for Toxic Plants. Journal of Medical Toxicology, 17: 42–47.
25. Peteinatos, G.G., Reichel, P., Karouta, J., Andújar, D., Gerhards, R. (2020): Weed Identification in Maize, Sunflower, and Potatoes with the Aid of Convolutional Neural Networks. Remote Sensing, 12(24): 4185.
26. Petit, S., Boursault, A., Le Guilloux, M., Munier-Jolain, N., Reboud, X. (2011): Weeds in agricultural landscapes, A review. Agronomy for Sustainable Development, 31: 309–317.
27. Reda, M., Suwwan, R., Alkafri, S., Rashed, Y., Shanableh, T. (2022): AgroAId: A Mobile App System for Visual Classification of Plant Species and Diseases Using Deep Learning and TensorFlow Lite. Informatics, 9(3): 55.
28. Sfar, A.R., Boujemaa, N., Geman., D. (2013): Identification of plants from multiple images and botanical IdKeys. In: Proceedings of the 3rd ACM conference on International conference on multimedia retrieval, Association for Computing Machinery, New York, NY, USA, 191–198.
29. Siddiqua, A., Kabir, M.A., Ferdous, T., Ali, I.B., Weston, L.A. (2022): Evaluating Plant Disease Detection Mobile Applications: Quality and Limitations. Agronomy, 12(8): 1869.
30. Zimdahl, R. L. (2007): Weed-crop competition: A review. Wiley-Blackwell, Iowa, USA.

Internet references:

1. https://apps.apple.com/us/app/plantme-ai-plant-identifier/id1532875668 (September 6, 2023)
2. https://blossomplant.com/ (September 6, 2023)
3. https://ec.europa.eu/eip/agriculture/en/find-connect/projects/need-identify-plants-or-trees-around-you-use-your.html (September 6, 2023)
4. https://hal.science/hal-02096020 (September 6, 2023)
5. https://myplantin.com/ (September 6, 2023)
6. https://myplantum.com/ (September 6, 2023)

8. Summary

The research was done with the goal of proving whether mobile applications for plant identification can recognize segetal and ruderal weeds, as well as comparing which mobile applications produce the most accurate findings. The identification is based on 94 pictures of seven weed species obtained in eastern Croatia. To identify weeds, five mobile applications (PlantNet, Blossom, PlantIn, Plantum, and PlantMe) available on Google Play and the App store were employed. The PlantNet application provided the best identification result with an accuracy of 95.74%, while the PlantIn application provided the lowest identification result with an accuracy of 60.64%. In addition to the best results, the PlantNet application provides users with another significant benefit over other applications, it is free from the start and for an extended length of time.

Key words: identification, image recognition, mobile application, weeds, segetal flora, ruderal flora

9. Sažetak

Istraživanje je provedeno s ciljem da se dokaže mogu li mobilne aplikacije za identifikaciju biljaka prepoznati segetalne i ruderalne korove, te je uspoređivanje koje mobilne aplikacije pokazuju najtočnije rezultate. Identifikacija je temeljena na 94 fotografije sedam korovnih vrsta slikanih na području istočne Hrvatske. Za identifikaciju korova korišteno je pet mobilnih aplikacija (PlantNet, Blossom, PlantIn, Plantum i PlantMe) dostupnih putem Google Play-a i App store-a. Najbolji rezultat identifikacije daje aplikacija PlantNet s točnosti od 95,74 %, dok najgori rezultat identifikacije daje aplikacija PlantIn s točnosti od 60,64 %. Uz najbolji ostvaren rezultat aplikacija PlantNet nudi korisnicima još jednu veliku prednost naspram drugih aplikacija, a to je da je ona besplatna od samog početka i na daljni period korištenja.

Ključne riječi: identifikacija, prepoznavanje slika, mobilna aplikacija, korovi, segetalna flora, ruderalna flora

10. List of figures

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Faculty of Agrobiotechnical Sciences Osijek
University Graduate Studies, Digital Agriculture, Plant production

A comparison of accuracy of image recognition apps for identification of segetal and ruderal flora

Davor Bilić

Abstract

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Usporedba točnosti aplikacija za prepoznavanje slika za identifikaciju segetalne i ruderalne flore

Davor Bilić

Sažetak

Istraživanje je provedeno s ciljem da se dokaže mogu li mobilne aplikacije za identifikaciju biljaka prepoznati segetalne i ruderalne korove, te je uspoređivanje koje mobilne aplikacije pokazuju najtočnije rezultate. Identifikacija je temeljena na 94 fotografije sedam korovnih vrsta slikanih na području istočne Hrvatske. Za identifikaciju korova korišteno je pet mobilnih aplikacija (PlantNet, Blossom, PlantIn, Plantum i PlantMe) dostupnih putem Google Play-a i App store-a. Najbolji rezultat identifikacije daje aplikacija PlantNet s točnosti od 95,74 %, dok najgori rezultat identifikacije daje aplikacija PlantIn s točnosti od 60,64 %. Uz najbolji ostvaren rezultat aplikacija PlantNet nudi korisnicima još jednu veliku prednost naspram drugih aplikacija, a to je da je ona besplatna od samog početka i na daljni period korištenja.

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