scientific reports

OPEN

Agriculture applications contribution to improve precise pest management in China

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The rapid proliferation of agricultural applications (apps) in China's digital village initiative necessitates systematic evaluation of their functionality and accessibility. Regarding the agricultural pest control apps that can be searched in the Chinese market, this study collected and analyzed information using 18 variables, involving developers, languages, application systems, identified objects and functions. There were 158 apps that met the 11 mandatory features, and most of the applications were developed for Android and iOS systems. The functions, accuracy, response time and goals of agricultural apps are all important factors affecting the download and application of agricultural apps. Identification apps are in the initial stage, while comprehensive application apps are gradually increasing. Regional or National, even of crop-specific pest management apps are becoming mainstream. Case studies of prominent Chinese apps provide critical services such as disease diagnosis, pest control recommendations, and farm management solutions, leading to quantifiable benefits including reduced pesticide use, decreased crop losses, and increased farmer income in China. Agricultural applications accessible via smartphones have great potential in preventing crop losses and reducing pesticide use. The development of agricultural pest and disease control applications still has a long way to go, including precise assessment and potential risks during the implementation process. There is no doubt that against the backdrop of the continuous growth of the global population, these applications will facilitate the digital prevention and control of agricultural pests.

Keywords Apps, Agriculture, Release, Function, Targets, Response time

With the rapid development of advanced technology, big data has permeated various fields. Big data applications in agriculture are also widespread, such as gene banks, integrated field systems, and the Internet of Things (IoT) from field to table. By collecting and analyzing massive amounts of data, farmers and agribusinesses can achieve precision breeding, precision agriculture management, forecasting and controlling pests and diseases, adjusting market strategies, etc., thereby reducing costs, improving yields and product quality, and promoting the modernization and sustainable development of agriculture. For instance, AgSpace can connect its business with thousands of farms around the world through a mobile scouting app and web platforms, which targets bespoke precision agronomy products to its farmers and grower customers to learn about the output of their land, as well as businesses and research (https://agspace.com/innovation/). Integrated Farming Systems (IFS), launched by the Monsanto Corporation, is a suite of digital tools which collects and analyzes farm data (https://www.farmprogress.com/farm-business/monsanto-integrated-farming-system). Chinese wheat growers have been found to have improved crop yields, net income, and return on investment by using smartphones[1].

At a time when smart agriculture is booming, accurate and efficient identification of plant pests and diseases is crucial for achieving green, healthy and sustainable agriculture. With the rapid development of deep learning technology in the field of image processing, the method of using deep learning to identify crop diseases from images have gradually become mainstream and has been incorporated into agricultural application software already on the market[2]. As a large agricultural country, China plays a critical role in global agricultural development and production. Most Chinese agricultural apps have been augmented by big data

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from the internet to collect key information on plant identification and classification, crop pests and diseases, soil conditions, and weather impacts, and use advanced analytical tools to interpret the collected information and provide farmers and those in need with appropriate advice on crop management and pest control measures. These apps have greatly improved the efficiency and sustainability of agricultural production. Data from the "48th China internet Development Statistical Report" shows that as of June 2021, China had more than 1 billion internet users, with the country ranking first for the number of netizens in the world. Undoubtedly, the use of the Internet and digital technologies embracing the Internet, IoT, cloud computing, and blockchain, have all positively contributed to agricultural growth. Benyam et al.[3] and Lioutas et al.[4] found that the internet and communication technology improve green agricultural productivity. Digital agriculture will enhance the green production efficiency of agriculture by promoting agricultural technological innovation and expanding the scale of agricultural production via improving the utilization rate of land resources, land transfer rate, reducing the use of agricultural fertilizers and pesticides to a certain extent[5].

The possibilities for farmers to utilize smartphones for their farm business have evolved over time in congruence with the development of the computing capabilities and functions of mobile phones[6]. Smartphones make communications much easier, reducing the impact of distance and other geo-barriers, with services such as biometric technologies, online business and precision agriculture.

Agricultural applications are transforming stakeholder engagement (including farmers and agricultural extension workers) across the agricultural value chain by providing real-time weather alerts, market intelligence, and AI-driven pest and disease diagnostics[7]. This technological shift is particularly crucial for pest management, as digital tools can help address the 20%–40% annual global crop losses caused by pest[8]. The economic implications are even more profound, with pests and pathogens reducing yields (typically by 17–30% for staple crops) while simultaneously compromising product quality and market value[9].

Against this backdrop, this study has examined the current landscape of agricultural applications. A thorough analysis will clarify technological developments and trends in pest management and provide decision-making references for agricultural informatization and intelligent. This research bears significance for advancing China's agricultural production intelligence while contributing to our understanding of digital transformation pathways and the evolution of smart technology applications in the agricultural sector.

Materials and methods

Collection and data compilation

This scoping review systematically examined mobile agricultural applications available in mainland China. The most common operating systems for smartphones in China are Android and Apple iOS regardless of the various smartphone brands. For this study, data was collected through several steps. First, by logging into the Android App Gallery and the Apple Store, we searched (via the search box) to find agricultural apps using a series of key words. Specifically based on the Chinese Agricultural Science Thesaurus and insect pest and disease management including identification, treatment, the following key words were used for the search: plant, pest, management, identification, plant protection. For robustness, the same key words were also used to search for agricultural apps on the CNKI database (China National Knowledge Infrastructure database) (http://www.cnki.net). The literature screening criteria are limited to peer-reviewed journal articles published till 2023, and the full text must be accessible.

Data sorting

To be included in this study, each agricultural app was required to provide the following 11 information variables: the app name, developer, app type (phone, WeChat, internet), software (Android or Apple), languages, development stage, single/multiple recognition, organism category (plant, animal, microorganism), the representative recognition target, response time and the function of the app. In addition, we also had 7 additional and optional variables/information that we collected as follows: if app is publicly available or not, number of organisms identified, organism developing stage, average recognition accuracy, quantity of images, release date and number of downloads. Using this criterion, we found 158 Apps (as of March 2023) meeting the 11 required fields. Study findings will be presented for these, but it should be noted that we provide for the optional variables, with the findings being less than the 158 total apps as not all apps had the optional information. For example, there were 144 apps with publicly accessible information and only 39 apps with download information. SPSS 19.0 was used to sort and summarize the different variables. Origin Pro was used to make figures.

Results

Overview of digital agriculture tools in China

Developers and languages

The analysis indicated that the vast majority (154, 97.47%) of the 158 agricultural apps were developed independently by their respective developers, with joint development not common. The developers could be divided into five different categories: research institutions, universities, companies, private individuals and government agencies. Companies and private individuals developed 83 (52.53%) and 51 (32.28%) of all the apps in the study. Half of the apps designed by universities are not publicly accessible and instead were published in peer-reviewed journals and theses. Research institutions were very active and collaborated with different types of developers except private individuals.

In terms of the languages, there were 59 different languages used. The top 10 languages were English, Chinese, French, Spanish, German, Japanese, Russian, Portuguese, Italian, and Dutch. Of the 158 apps, the majority, 106 (67.08%), were in or had English as a language and a large proportion, 85 (53.79%), were in or had Chinese as a language. Secondly, the same app could be available in a single language or different languages. The former accounted for the majority of the apps, with 101 (63.92%) out of 158 Apps (63.92%) (Fig. 1). Specifically, 48 (30.3%) single-language apps were designed in English and 52 (32.9%) in Chinese. English language apps were primarily designed for iOS, while Chinese apps were mainly designed for the Android system. Over 91.67% of the single-language English apps relied on Apple systems, and more than 67.31% of the 52 single-language Chinese apps were dependent on Android systems. For the apps that were developed and designed in China, the Android system was often preferred due to its openness and widespread popularity among users. This preference may also have stemmed from specific features of the Android operating system that catered to the needs of Chinese developers and users.

Regarding multiple-language apps, the top three were all designed by Aleksei Metelkin, named Plant Disease Identifier, Mushroom identification, and Plantr-Plant Identifier (https://www.appbrain.com/appstore/plant-disease-identifier/ios-1550499292; https://apps.apple.com/cn/app/mushroom-identification/id1561107001?l=en-GB; https://www.appbrain.com/appstore/plantr-plant-identifier-app/ios-1514771005). These three apps were available in 32 different languages, including English, Arabic, Catalan, Croatian, Czech, Danish, Dutch, Finnish, French, German, Greek, Hebrew, Hindi, Hungarian, Indonesian, Italian, Japanese, Korean, Malay, Norwegian Bokmål, Polish, Portuguese, Romanian, Russian, Chinese (Simplified and Traditional), Slovak, Spanish, Swedish, Thai, Turkish, Ukrainian, and Vietnamese. Those three apps were developed for the iOS system based on computer vision and machine learning tools, which consistently received and considered user experience feedback, addressed any usage issues, improved software performance, optimized the design layout, and were committed to developing software that fully satisfied users. However, the designers kept the unique characteristics of each app. For instance, Mushroom Identification and Plantr-Plant Identifier had an extensive database, with an identification accuracy of up to 98%, which demonstrated their excellent practicality and efficiency. The Mushroom Identification app could assist in identifying mushroom species to prevent accidental ingestion of poisonous species. Cases of mushroom poisoning would also receive special attention. The Plantr-Plant Identifier app could not only identify any plant along with its encyclopedia information but also provide plant care reminders, including setting watering frequency reminders tailored to users' needs. The Plant Disease Identifier app offered information on over 30 plant diseases and possible treatment options, such as applying fertilizers correctly and safeguarding the environment (https://Apps.Apple.com/us/App/mushroom-identification/id1561107001, https://Apps.Apple.com/us/App/plantr-plant-identifier-App/id1514771005, https://Apps.Apple.com/us/App/plant-disease-identifier/id1550499292).

Apart from Aleksei Metelkin, the other top app developers were Next Vision Limited (3 apps), Quantty LTD (3 apps), and Bai xiaoming (3 apps). Next Vision Limited is an industry-leading AI company specializing in computer vision and NLP, committed to bridging nature and life through AI technology (https://www.thevisionext.com/). It has created apps that support multiple languages, with 2 of the 3 apps supporting 21 languages, including English and Chinese (Simplified and Traditional). Quantty LTD, which is based in the UK, is engaged in engineering-related scientific and technical consultation activities (https://opencorporates.com/companies/gb/09573923). The apps it developed were only available in English. Bai xiaoming, as a developer, solely focused on iOS system apps in Chinese.

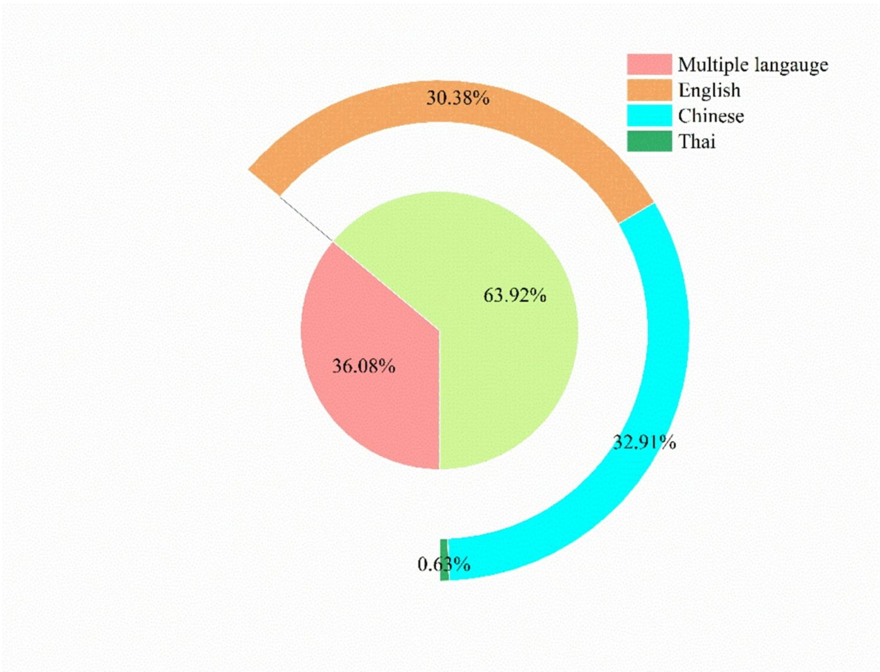

Fig. 1. The languages of the 173 agricultural apps.

Accessibility and release year of agricultural apps
Users could download and obtain information from three sources, in the order of priority: webpage/internet, smartphone app stores, and publications (peer-reviewed journals, theses, and conference proceeding reports) (Fig. 2). With computers and laptops widely used, the internet remained the primary approach to obtaining different agricultural apps. Besides the internet, smartphone apps have shown a strong trend of development, especially in regions with limited internet access. Additionally, some of the apps could be obtained from more than one source, such as through academic journals and webpages, or directly from smartphone app stores and online platforms.

Just over half, 83 (52.5%) out of the 158 agricultural apps provided release years. The number of apps released has increased over the years, encompassing an initial period (before 2019) and a rapid growth period (2019 onwards, 61 apps). The first peak occurred in 2019, with 12 apps released. Additionally, 22 apps were released in 2021. During the rapid growth period, apps in English and Chinese were significantly more popular than others.

Target organisms of agricultural apps
The main organisms targeted by the agricultural app were plants, animals and microorganisms (Table 1). Most of the apps were available for public use (144 out of 158, 91.14%). A few, however, were not available for public use, being developed by different universities, which had been published through journal papers but remained incomplete. Further analysis was conducted only for the 144 publicly accessible apps.

The apps targeting plants were divided into 4 categories: ornamental plants, agricultural crops, invasive plants, and wild plants. Most plant apps focused on more than one plant category, with only a few apps for only a specific plant type. Relevant ornamental plant apps were the most numerous (132) including specific ornamental plant apps (16), followed by agricultural crops (120) including specific crop apps (5) (Fig. 3). Moreover, Animal apps were focused either on single or multiple targets and could be divided into insects and other animals. The specific insect apps accounted for more than half of the relevant insect apps, mainly concerning insect pests in agroforestry production.

The growth period and developmental stage of the targets for identification vary with their taxa. When it came to plant identification apps, leaves often serve as the primary identification objects. Leaf traits, while easy to extract, could be vulnerable to environmental influences, and different species may exhibit similar traits due to environmental adaptation. Leafsnap, the inaugural mobile app for plant species identification through automatic visual recognition, could identify tree species from photographs of their leaves. In contrast, for animal

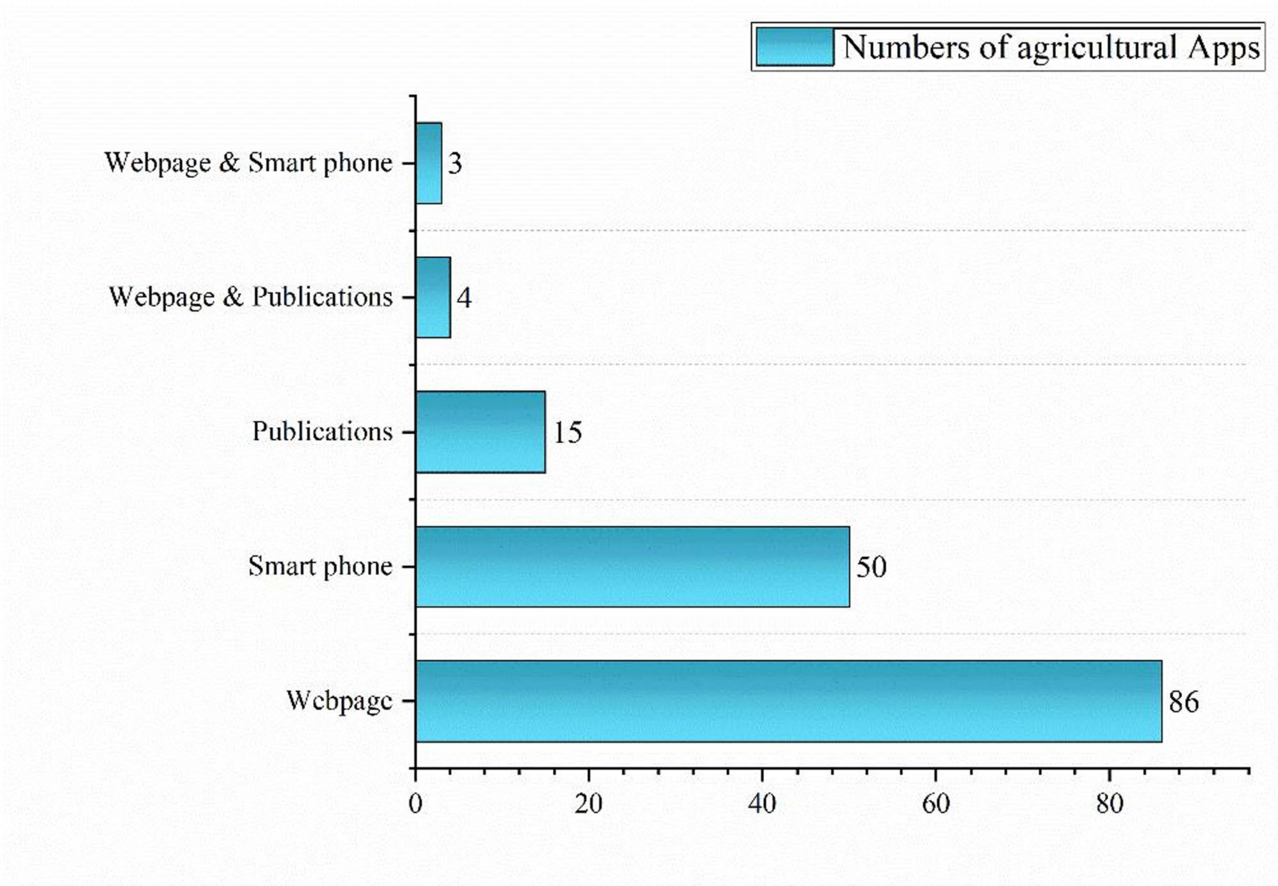

Fig. 2. Approaches to acquiring different apps.

Organism type	All apps	%	Open access app	%
Plant	102	64.56	94	59.49
Animal	15	9.49	11	6.96
Microorganism	3	1.90	2	1.27
Plant & animal	26	16.46	25	15.82
Plant & microorganism	7	4.43	7	4.43
Animal & microorganism	1	0.63	1	0.63
Plant, animal & microorganism	4	2.53	4	2.53
Non open access	/	/	14	8.86

Table 1. The target organisms of different apps.

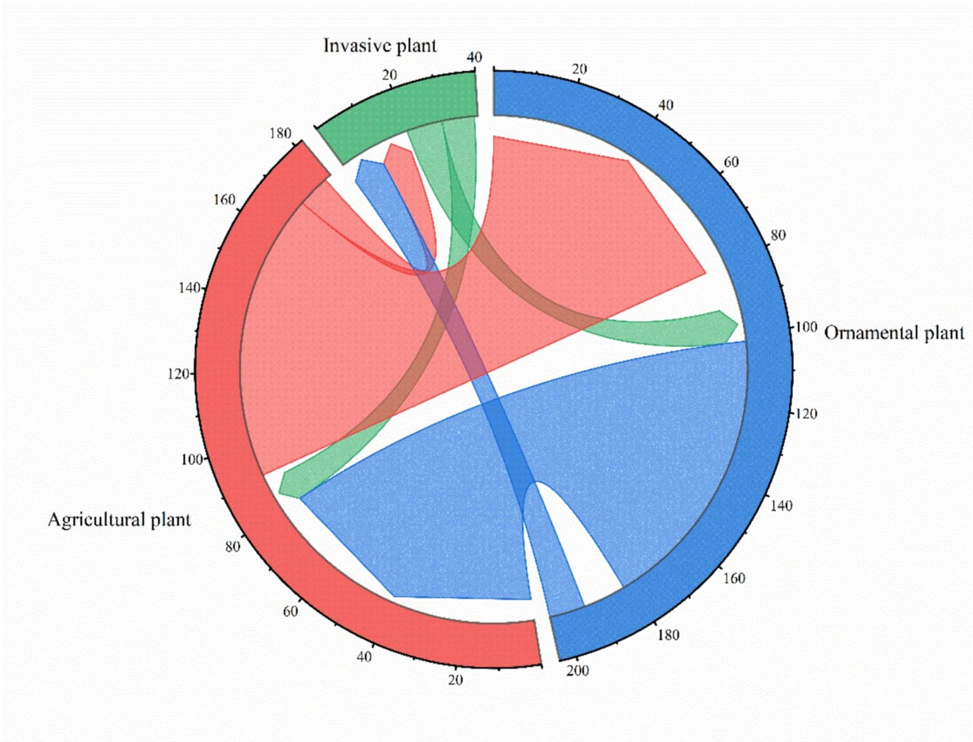

Fig. 3. Types of plant apps.

identification apps, insects are primarily recognized in their adult stage, with less focus on larvae and eggs. For other animals, facial recognition often plays a crucial role in identification.

Download status of agricultural apps

Thirty-nine out of the 158 agricultural apps provided release years which allow free download for the public. Apps with 10 K + downloads constituted the highest proportion (17 out of 39, accounting for 43.6% of the total), followed by apps with 100 K + downloads (8 out of 39, accounting for 20.5% of the total), as depicted in Fig. 4.

Among the apps with 10 K + downloads, 11 were plant-focused, and primarily focused on ornamental plants (horticultural plants), including Weiruanshihua, Paizhaoshihuajun, Huacaojun, FlowerChecker, and GardenTags. Specifically, Weiruanshihua, an offline portable plant expert, represented an interdisciplinary academic collaboration between Microsoft Research Asia (MSR Asia) and the Institute of Botany, Chinese Academy of Sciences. It was founded on the iterative training of 2.6 million flower images (https://paper.sciencenet.cn/htmlnews/2016/9/357431.shtm). GardenTags, developed by 4D Media Limited in 2017, is a flower app that catalogues 25,000 plants, providing users with information on plant identification, planting advice, and plant care (https://Apps.Apple.com/us/App/garden-tags-plant-advice-care-identification/id852472656?xcust=1651801756399bOsa&xs = 1). This was followed by two insect-related apps, *Zhibaojia* (植保家) and *Henzhun Shi'e* (很准识蛾), as well as four apps that did not mention objects. *Zhibaojia*, developed by Beijing Lianxin Times Technology Co., Ltd., a company specializing in software development and technology promotion, has been available since 2018 and has provided free access to nearly 100,000 users. Presently, it possesses the capability to recognize common diseases in wheat, tomato, pepper, peach, and pear trees, as well as common pests affecting garden plants. A total

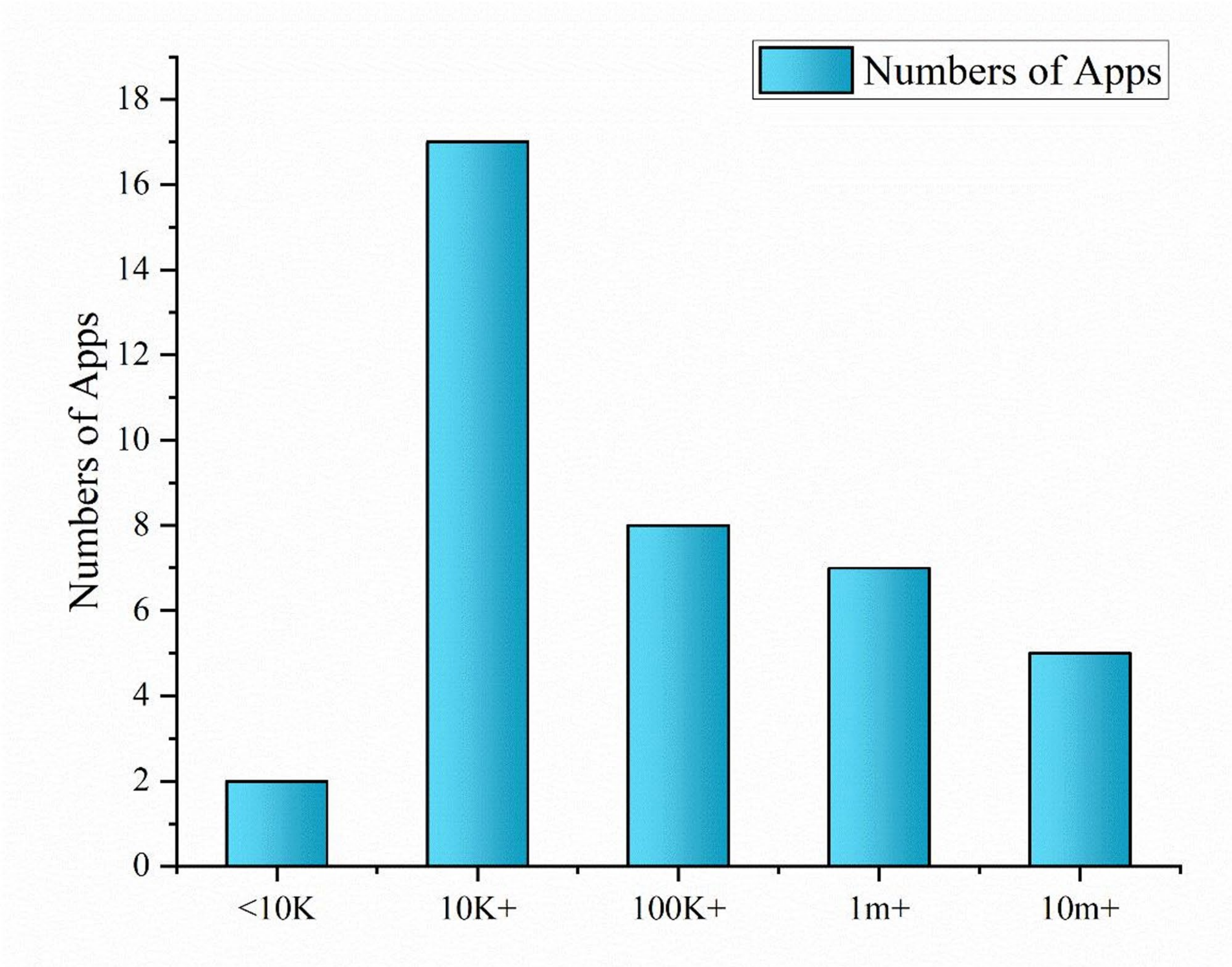

Fig. 4. The distribution of apps in different download ranges.

of 212 significant diseases could be identified across 39 crop types, utilizing a comprehensive dataset comprising 22,980 pictures of diseases and insects. This application facilitated the identification, prevention, and control of diseases and insect pests in key agricultural products, thereby realizing the aspiration of benefiting farmers through the application of science and technology (https://Apps.Apple.com/cn/App/%E6%A4%8D%E4%BF%9D%E5%AE%B6/id1440712927). *Henzhun Shi'e*, a plant protection app specializing in the prevention and control of the fall armyworm, was introduced in 2019, leveraging the advancements in mobile internet and big data technologies. Developed by Beijing Puhui Sannong Technology Co., Ltd., which primarily offered technical services, technology transfer, development, software development, and data processing, the app had an accuracy rate of more than 90% for moth identification. This achievement provided scientific and effective prevention and control measures, enabling early detection, warning, and control of fall armyworm (https://country.people.com.cn/n1/2019/0718/c419842-31243174.html, https://Apps.Apple.com/mu/App/%E5%BE%88%E5%87%86%E8%AF%86%E8%9B%BE/id1473684843).

Factors related to app downloads

Function of the agricultural apps

Flora and fauna offered a wide range of functionalities, including identification, search, question and answer, prevention and treatment, geographic map display, maintenance, interactive communication, and shopping. The apps with recognition and identification functions made up the main body of agricultural apps, accounting for 39.0%. Users can simply take a picture with the app and wait for the name of the flora or fauna to be displayed. For example, the Lily-Plant Identification app, developed by Apple in English and launched in 2021 has six different functions, and aims to provide innovative technology services to people who like these plants (https://Apps.Apple.com/us/App/lily-plant-identification/id1570145257).

Volume of identification apps

In terms of species count, with a thousand as the fundamental unit, designers and institutions tended to prioritize apps that could identify 10 K species, considering the usage and costs, followed by apps that could identify 1 K

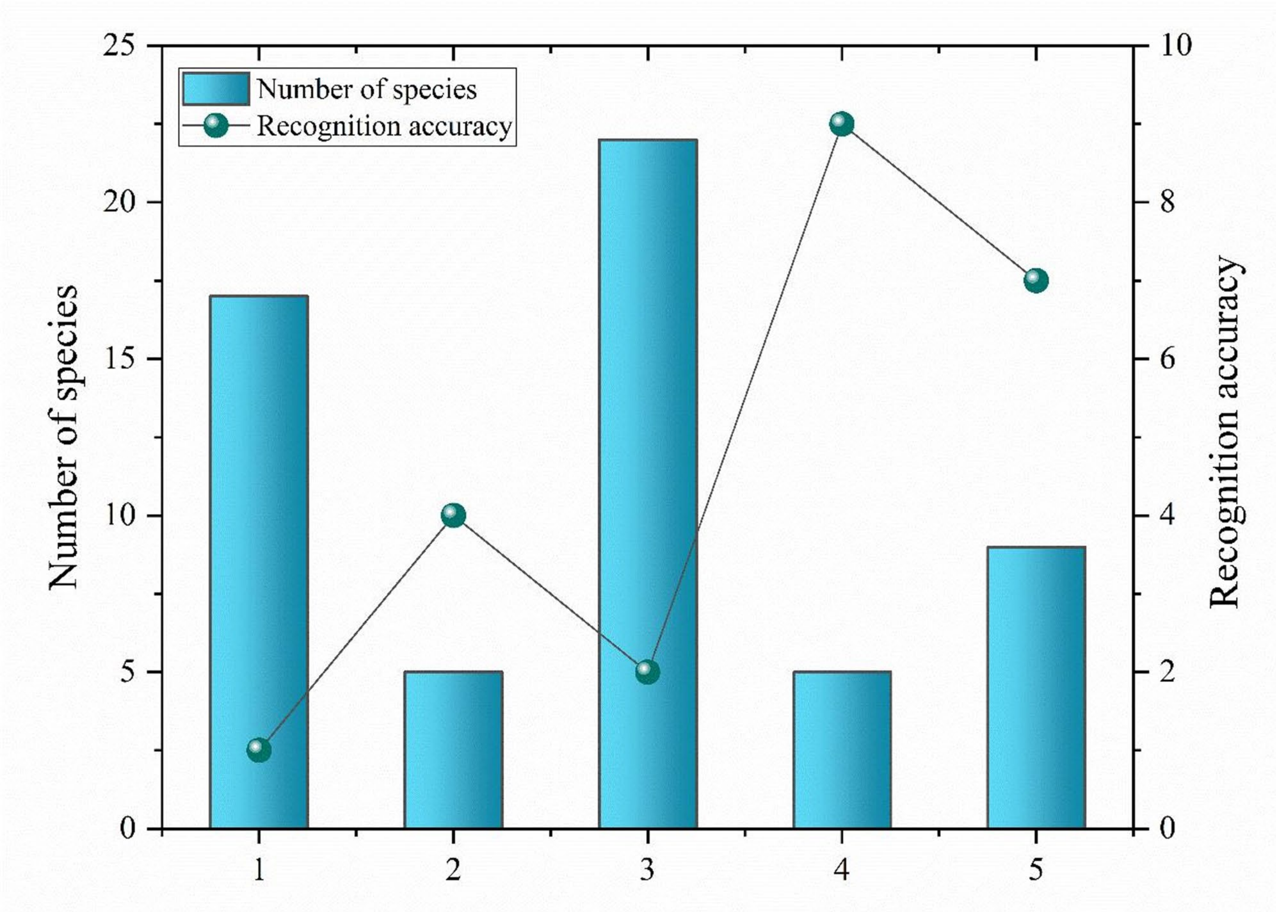

Fig. 5. The number of species and recognition accuracy of apps. Note: Categories 1–5 represent ≤ 1 K; >1 K; >10 K; >100 K; >1 mill. species and ≤ 80%; 80%~85%; 85%~90%; 90%~95%; >95% recognition accuracy respectively.

species (Fig. 5). Among the apps capable of identifying 10 K + species, over half were developed by companies, while approximately one-third were created by individuals.

With profit as the goal, companies prioritize visual experience, technological advancements, and interface design, requiring significant financial backing and team collaboration. Furthermore, there were 11 apps capable of identifying over 1 million species. For instance, Plant Identification and Care app could identify 98% of known plants, flowers and trees covering most species encountered in every country on Earth. This was regarded as the largest number of species identified and also offered plant care and the ability to create a personal collection.

Datasets serve as the fundamental cornerstone for the application and development of apps. In recognition applications, images were the most important resource, and their importance was reflected in the quantity and quality of images. The recognition ability of an application was directly related to the amount of database accumulation, the more the accumulation, the stronger the recognition ability. For instance, Merlin Bird ID, developed by Cornell Lab, stands as the world's premier bird identification app, capable of identifying any bird species regardless of location. Not only does the app have a database of over 1 billion bird observations globally, but it also supports multiple languages including English, Spanish, Portuguese, French, Hebrew, German, Japanese, Korean, Turkish, and Chinese (https://Apps.Apple.com/us/App/merlin-bird-id-by-cornell-lab/id773457673).

Accuracy of identification

The accuracy of identification in flora and fauna identification apps is a crucial metric that determines their utility and user experience. A total of 21 apps provided recognition accuracy information, and almost all of them were above 80%. Notably, 13 apps achieved recognition accuracies of 95%+ (Fig. 5), with two, Plant Identifier-Free of ADS and PlanTR-Plant Identifier app, achieving accuracy of up to 99%; the former employing an AI-powered system to identify over 1 million plants with 99% accuracy in mere seconds. Beyond recognition and treatment advice, it also offered plant care advice, personal collection creation, and English language support (https://Apps.Apple.com/no/App/plant-identifier-free-of-ads/id1617336140). The latter app was also an AI-driven application, able to identify any plant with 99% accuracy, providing plant care advice and supporting 32 languages (https://Apps.Apple.com/us/App/plantr-plant-identifier-App/id1514771005).

Selected application cases of agricultural apps from China

"Huizhinongdangjia" App, previously named "Zhixiaobao", focuses on agricultural crops covering staple crop, vegetables, fruit trees, and cash crops. The functions include disease and pest diagnosis, expert services, and the digitalization of the agricultural supply chain in the agricultural sector. This App contains diseases (675), insect pests and symptoms of damage (639), weeds (39), natural enemies (15) from 28 different crops, and the field identification accuracy rate reaches 94.57%. With 5-minute expert Q&A consultations, the response rate is 99%. During the COVID pandemic period, customized pest control plans were provided to farmers via the "online consultation + online prescription" model, covering 660,000 ha of farmland nationwide, helping 4 million farmers reduce production costs. *Empoasca pirisuga* Matumura is a key pest in the tea garden. This App helped one tea farmer in Zhejiang Province, China, and generated a precise control plan of "yellow sticky traps + Bifenthrin spraying" combined historical data and meteorological information. After implementation, the density of *E. pirisuga* decreased by 78%, the qualified rate of tea pesticide residue detection increased to 99.2%, and each ha of land increased income by approximately 18,000 Chinese yuan. The operation of the application starts with disease and pest identification and planting production services and is suitable for all types of farmers and agricultural enterprises to adopt with a combination of free and paid services. (https://apps.microsoft.com/detail/xp8lk8brvk21q5?hl=zh-CN&gl=CN)

Plant Guardian App, designed for garden maintenance scenarios, focuses on monitoring, identification, early warning, query in Wuhan City, Hubei Province, China. Most functions are completely free except advanced functions (such as customized monitoring reports), which are only available to government departments and large enterprises. Once users take a photo to identify various insects and diseases, they receive intelligent recommendations for control methods. This App contains information on over 930 garden pests in the Central China and can identify 540 common garden pests in Wuhan City with over 92.7% accuracy. The App regularly releases forecast and prediction information for public. The residents in that region benefit from the App for ornamental plants with the guidance of the insects and diseases management. In terms of afforestation of city, the App played a vital role in identifying Camphor-tree Yellowing. It not only accurately determines the cause (iron deficiency physiological disease) but also provides soil improvement plans and leaf fertilization suggestions, resulting in a 30% improvement in control effect compared to traditional experience methods. (https://apps.apple.com/tw/app/plant-guardian-grower-edition/id6477366390)

MAP ZHINONG App focuses on the development of smart agriculture providing modern farm management comprehensive solutions centered on precise planting for large-scale growers, which belongs to Modern Agriculture Platform of the Sinochem Group Co., Ltd. This App assist farmers in achieving scientific farming through functions such as remote sensing field inspections, precise weather forecasting, and pest and disease warnings. For instance, its remote sensing technology can reduce the field inspection time for large-scale growers from 1 to 3 days to 30 min. It automatically alerts and provides diagnostic prescriptions based on 122 disease and 326 pest, 419 weeds identification models for crops such as rice, wheat, maize and citrus, with an accuracy rate exceeding 85%, and achieves water and fertilizer savings through digital water and fertilizer algorithms. The monitoring coverage of walnut pests and diseases at Lin'an District of Hangzhou City, Zhejiang Provenience, China increased from 60% to 100% through this platform. The rice farmer in Hubei Province, China reduced the pesticide usage by 15% after using the APP, saving about 12,000 Chinese yuan per ha yearly. MAP ZHINONG App has established over 600 MAP technology service centers nationwide, providing offline service area that exceeds 1.86 million ha, resulting in a 1.2 billion kg increase in grain production and increasing farmers' income by over 3 billion yuan annually till 2022. This App is with a combination of free and paid services. (https://apps.microsoft.com/detail/xp9m0n7nmm6r7h? launch=true&mode=full&hl=zh-cn&gl=cn&ocid=bingwebsearch)

Discussion

The rapid global proliferation of smartphones has profoundly transformed both learning and daily life[10], with mobile applications playing pivotal roles across multiple domains including education, scientific research, and agriculture[11,12] (https://www.statista.com/statistics/720062/market-value-smart-agriculture-worldwide/). These applications further enable precision agricultural practices, such as variable-rate fertilization and pesticide application based on GPS[13] and sensor data, significantly reducing resource waste[14,15]. Currently, such technologies have achieved relatively widespread adoption in large-scale farms within developed countries (e.g., 45% of corn acreage in the U.S. utilizes variable-rate technology) (https://www.ers.usda.gov/publications/pub-details? pubid=93025), while remaining less prevalent among smallholder farmers (e.g., merely 21% GPS adoption rate on Canadian farms under 500 acres) (https://www150.statcan.gc.ca/n1/pub/95-640-x/2016001/article/14816-eng.htm).

As an essential component of modern agricultural technology, agricultural applications serve as crucial tools for advancing smart and precision agriculture. These applications not only create opportunities for rational pesticide use and reduction targets[16,17], but also effectively promote agricultural sustainable development through optimized resource utilization. Functionally, they provide farmers with convenient and efficient agricultural information services, despite varying definitions across contexts.

This study focuses specifically on the developmental landscape of agricultural applications in China, encompassing both traditional farming practice solutions and ornamental plant cultivation applications. Through these smartphone-based tools, Chinese farmers can access real-time agricultural updates, market trends, and practical guidance on pest and disease management tailored to local conditions.

After analyzing 158 agricultural apps found in the China mobile App stores, we find that agricultural apps suitable for mobile phones show a trend of becoming mainstream. This is largely in part due to the large number of mobile phone and internet users in China. In addition, the initial focus of agricultural apps was on flowers rather than pest and disease control for crops. Overtime however, the objects covered by agricultural apps have expanded to include butterflies, pests and diseases, invasive species, etc. It is worth pointing out, while biometric applications have simplified the process of identifying plants and animals and reduced the amount of tedious work involved, they are only an aid to observing plants and animals. Moreover, the accuracy of plant and animal identification applications needs to be improved and cannot replace professionally trained experts in biodiversity research or ecological surveys[18].

Apps for agricultural pest control require more data support and more investment. This is because these types of Apps need to target a specific or category of harmful organisms. After all, digital simulation has uncertain variables in the complex real environment. However, with the development of technology, the loopholes in this aspect will be gradually filled. Evidence exists indicating that agricultural production and local farmers are benefiting from the use of digital and AI tools that have pest and disease diagnostic functions. examples include Jiangsu and Zhejiang Province, where digital technology has developed rapidly, with local farmers benefiting from the use of agricultural apps, with significant yield increases attributed to AI regulation of water and fertilizer (savings of 30% of in water use and increased yields by 15%). Modern agriculture has also generally achieved precision in crop cultivation through remote control technology. Agricultural Apps are also in use for crop pest and disease identification and treatment[19,20]. Thus, agricultural apps have become indispensable tools for farmers as they not only improve their production skills and management levels but also promote the development of information technology and intelligence in agriculture. By using these apps, farmers are better able to manage their crops more efficiently and improve yield and quality[19].

Despite all the documented benefits, key challenges exist with the use of agricultural App and issue of who bears the cost in the case of decision support tools that give erroneous advice, for example for crop pest treatment. These challenges and many others may limit App usage and downloads. To overcome this, it is critical that farmers using agricultural Apps should have access to support/guidance - remotely through the digital agriculture platform. App developers and promoters must ensure that subject matter experts (for example in crop pest diagnoses and management) should be available to provide farmers with support to achieve effective management and precise control of pests and diseases[21–23].

In practical agricultural field settings, mobile agricultural applications fundamentally rely on persistent wireless connectivity. However, current IoT systems predominantly utilize short-range communication technologies (e.g., ZigBee) with effective coverage radii typically limited to < 100 m (https://www.thingskit.com/37902.html), which proves inadequate for meeting the long-range monitoring requirements (> 500 m) of large-scale field environments. Although emerging long-range technologies including Long-Range Radio (LoRa) and Narrowband Internet of Things (NB-IoT) show promising potential, their base station deployment costs remain prohibitively high[24]. The successful transformation of agricultural applications therefore requires a coordinated dual-track strategy combining technological optimization to reduce communication infrastructure costs with comprehensive nationwide digital skills training initiatives for farmers. This integrated approach is ultimately designed to achieve synergistic improvements in agricultural productivity while promoting the adoption of scientific cultivation practices across diverse farming systems.

Conclusion

Agricultural apps via smartphone access have great potential to prevent crop loss and reduce pesticide use. The development of apps for agricultural pest control still has a long way to go, including precise assessment and potential risks during the implementation process. From the perspective of the source of the App, most developers attach great importance to practicality rather than publishing articles. This is the essence of an App. However, all the developers have, without prior agreement, not been involved in the profit model. Even though, under the context that global population continues to grow, so does the demand for food, which drives the adoption of these advanced technologies across the agricultural sector to increase productivity. While agricultural apps undeniably enhance farm management efficacy, their uncritical adoption risks exacerbating socioeconomic disparities and ecological harm. Future development must prioritize context-specific design over mere technical sophistication to authentically serve China's fragmented agricultural landscape.

Data availability

Data generated and collected in this study are not publicly available but are available upon reasonable request from the first author (Hongmei LI, E-mail: [h.li@cabi.org](mailto: h.li@cabi.org)).

Received: 6 September 2024; Accepted: 22 October 2025
Published online: 24 November 2025

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Acknowledgements

CABI is an international intergovernmental organization, and we gratefully acknowledge the core financial support from our member countries (and lead agencies) including the United Kingdom (Foreign, Commonwealth and Development Office), China (Chinese Ministry of Agriculture and Rural Affairs), Australia (Australian Centre for International Agricultural Research), Canada (Agriculture and Agri-Food Canada), the Netherlands (Directorate-General for International Cooperation), and Switzerland (Swiss Agency for Development and Co-operation). See https://www.cabi.org/what-we-do/how-we-work/cabi-donors-and-partners/(accessed on 20 August 2024) for full details.

Author contributions
H.L. wrote the main manuscript text, Y.C. and M.W. prepared Figs. 1, 2, 3, 4 and 5 and M.A.T.J.K., F.Z., U. D. and G.W. made comments on the draft version, Y.C. and T.Z. collated the references. All authors have read and agreed to the published version of the manuscript.

Funding

This work was supported by the National Key R and D Program of China (2023YFE0100100), the CABI Development Fund (IVM10051).

Declarations

Competing interests
The authors declare no competing interests.

Additional information

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