
# Advancements in Agricultural Robots for Specialty Crops: A Comprehensive Review of Innovations, Challenges, and Prospects

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***Abstract.***

*The emergence of robot technology presents a timely opportunity to revolutionize specialty crop production, offering crucial support across various activities such as planting, supporting general traits, and harvesting. These robots play a pivotal role in keeping stakeholders up-to-date of developments in their production fields, while providing them the capability to automate laborious tasks. Then, to elucidate the advancements in this domain, we present the results of a comprehensive review covering from 1988 to 2023, meticulously examining the state-of-the-art in robots for specialty crops. A rigorous search strategy was formulated, leveraging the Scopus® and Web of Science™ databases to ensure a thorough investigation. Careful selection of keywords such as "robot" and "specialty crops" was employed to enhance comprehension and comprehensiveness. Only peer-reviewed papers were considered, resulting in the inclusion of 706 papers. Each paper was meticulous evaluated by a panel of reviewers who evaluated various aspects including titles, abstracts, keywords, methods, conclusions, and declarations. Consistency and eligibility were predominant in determining which papers met the stringent inclusion criteria. Any discrepancies or disagreements were resolved through rigorous consensus-building discussions among the reviewers. The primary aim of this review is to contribute scientifically to the understanding of robots for specialty crops within the research landscape, elucidating current limitations and suggesting opportunities for future investigations. Our review highlights the multifaceted contributions of robotics for specialty crop agriculture, extending beyond mere technological advancements to encompass profound social sustainability implications. While advancements in harvesting technology have certainly been transformative, the real-world impact transcends efficiency advances. By integrating harvesting robots, we are not only revolutionizing methods but also reshaping social dynamics within agricultural communities. Finally, our insights serve to unravel the intricate dynamics of technological advancements within the field, while also supporting the cause of cultivating a more sustainable and resilient agricultural landscape for specialty crops production.*

***Keywords.***
*ground robots, fruits, vegetables, horticulture, literature review.*

## Background

Specialty crops encompass a diverse range of fruits and vegetables, tree nuts, dried fruits, and horticultural and nursery crops, including floriculture (USDA, 2024). Specialty crops typically maintain their freshness and nutritional integrity post-harvest. However, it needs careful cultivation practices to preserve the quality and flavor of the produce, as well as specialized handling techniques to maintain its market value (Vuppalapati, 2023). Given these challenges, there is a growing interest in leveraging technological advancements, particularly robotics, to enhance the cultivation of specialty crops (Barbosa Júnior et al., 2024). Firstly, robots are inherently adaptable and can be customized to suit the specific needs of different crops, environments, and farming practices. Moreover, robots offer precision in their operations, ensuring that tasks are performed accurately and consistently. Therefore, we aim to fill this gap by conducting an in-depth analysis of the scientific literature to provide a comprehensive review of robots for specialty crops. This review will offer insights into the latest advancements, challenges, and opportunities in the field, contributing to the ongoing discussion on the role of robotics in modern agriculture.

## Metodology

We conducted a meticulous review by diving into the contemporaneous literature of robots and specialty crops, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. We defined Scopus® and Web of Science™ as databases to retrieve scholarly items to elaborate on a driving bibliometric compilation. We arranged indexing terms and Boolean operators into a representative research engine string, i.e., [title-abstract-keyword = (robot OR unmanned ground vehicle OR UGV) AND (specialty crops OR fruits OR vegetables OR tree nuts OR dried fruits OR horticulture OR nursery crops)], to strike them. We focused our review on the period of 1988-2023 to refer to the broadest bibliographic collection, from the emergence of robots in the typical literature on specialty crops to the latest complete year of publication in both electronic databases. Our survey produced 3,480 potential studies. However, our reviewers (MB, RS, LS) independently assessed them for consistency and eligibility. They selected only studies fitting within our scope of operating robots for specialty crops, consciously excluding experiments on non-robot related support, duplicates to prevent bias, non-English, and any “grey literature” to the soundness of our approach. Therefore, 2,774 studies were removed. For the 706 remaining, we strictly filtered them by journal, country, crops, and subject.

## Results

All 706 eligible papers were thoroughly examined on an annual basis. Subsequently, the utilization of robots in the production of specialty crops, aimed at resolving daily challenges, has experienced a rapid surge in popularity (Figure 1). Particularly noteworthy is the pronounced escalation in the adoption of robot technologies within the realm of specialty crop production over the past decade, with notable peaks observed in 2022 and 2023. The trajectory of scholarly contributions in this domain has consistently demonstrated an upward trend, characterized by steady growth.

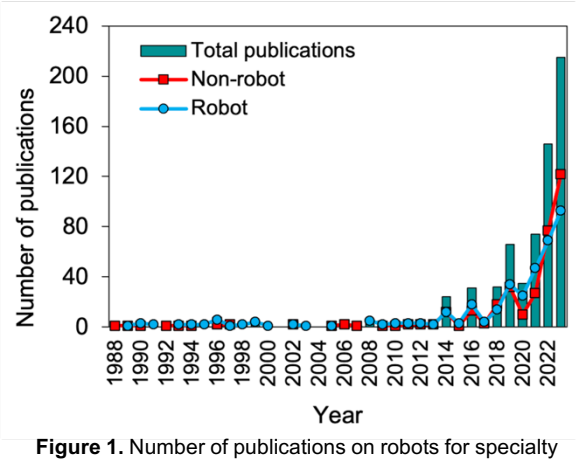


**Figure 1.** Number of publications on robots for specialty crops from 1988-2023.

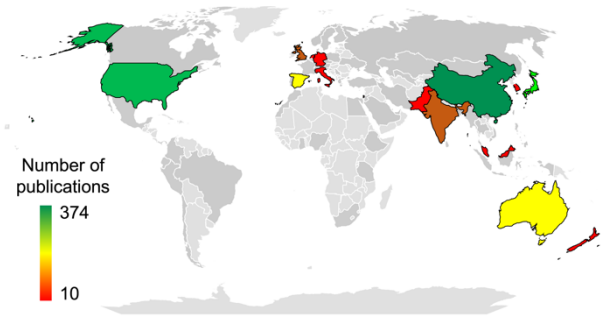


**Figure 2.** Number of publications worldwide on robots for specialty crops from 1988-2023.

From the global scientific collaboration, an active participation from all continents has been documented (Figure 2). In total, 68 countries across the globe have contributed to the scientific discourse in this field. China stands as a significant and prolific contributor, representing approximately 44% of the total publications, with a noteworthy mark of 374 papers. Following this, the United States occupies the second position with 88 studies and Japan in fourth with 53.

It is noteworthy that the primary focus of research in the domain of robots for specialty crops predominantly revolves around harvest applications (Figure 3). Approximately 80% of the investigated papers either utilized harvest robots or addressed applications related to their support. Conversely, other applications accounted for less than 3% of the overall research interest.

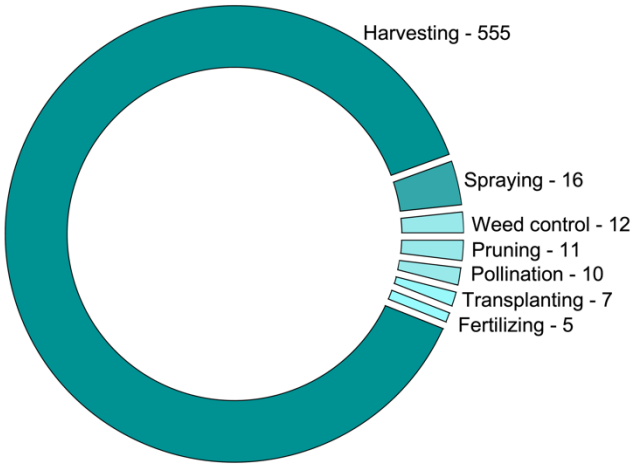


**Figure 3.** Number of publications on robots for specialty crops from 1988-2023 specifying the subjects.

## Conclusion

Robotic technologies enhance specialty crop production by improving precision and efficiency in harvesting, spraying, weed control, pruning, pollination, transplanting, and fertilizing. Robots reduce labor costs, increase uniformity, and adapt to various crops, improving yields and productivity. However, they face challenges such as limited generalizability across different crops, reliance on environmental conditions for accuracy, high computational resource demands, limited field testing, high acquisition costs, and insufficient data on effectiveness. Overcoming these requires ongoing R&D to enhance adaptability, efficiency, and reliability.

### Acknowledgments

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