

A new framework for horticultural research in botanic gardens and arboreta of the United States

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Abstract

Botanic gardens and arboreta maintain globally important collections for conservation and education. Many organisations hold a reputation for excellence in propagation, cultivation and collection preservation. Learning from successes and challenges, and having the ability to disseminate that knowledge, is paramount for improving techniques and outcomes. However, the field of horticultural research is not well defined, and results of plant cultivation techniques are often only shared informally rather than published. This study was designed to explore how horticultural research practitioners perceive the field of horticultural research and excellence, how they and their institutions are involved, and what are the most urgent needs of future horticultural research among gardens and arboreta in the United States. An online survey was distributed to ascertain the status of horticultural research amongst the United States members of the American Society for Horticultural Science, the American Public Gardens Association, Botanic Gardens Conservation International and the Interactive Community of Arboreta, Level II, III and IV members. The survey was completed by 128 respondents from 34 US states across 116 institutions. The responses highlight the fact that horticultural excellence is holistic – focusing on species conservation, ecology and pest mitigation. The findings also touch on the status and involvement of respondents in horticultural research and their perceived needs for future research. These responses further highlight challenges such as funding, time and personnel shortfalls. Horticultural research also includes an emphasis on practical approaches, requiring better recognition and sharing methods. The findings introduce a new framework to support the horticulture community in conceptualising, communicating and implementing research. This framework proposes that horticultural research can be broadly categorised into two overarching approaches: practical and technical.

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Introduction

Botanic gardens and arboreta are specialised institutions holding documented collections of living plants for the purpose of scientific research, conservation, display and education. These institutions are increasingly involved in conservation including the cultivation of endangered plants (Westwood *et al.*, 2021). Horticulturists and gardeners are both involved in the hands-on cultivation of plants, and participate in the act of horticulture, but a horticulturist is normally defined as a formally educated and trained professional with a broader understanding of plant science (Edmond *et al.*, 1957). A gardener may cultivate plants as a hobby or a profession and may or may not have had a formal education.

The American Society for Horticultural Science (ASHS) defines horticulture as a branch of agriculture concerned with the art, economics, management, practice, science and technology of producing non-commodity, labour-intensive, speciality plants cultivated for aesthetics, economics, food, medicine or other human benefit (ASHS, 2022). The focus of horticulture on producing such plants contrasts with agriculture, which, in many industrialised countries, relies on a high level of machinery use over an extensive area of land, consequently involving few people in the production process. However, the boundary between horticulture and agriculture is far from clear (Adams *et al.*, 2008).

There are many techniques involved in horticulture and some insights are gained through one's own experience of gardening (Adams *et al.*, 2008). Since horticulture is a unique combination of art and science (Durner, 2013), approaches to the field vary drastically. Further, there is a fundamental difference between production horticulture

and service horticulture, which includes the development and upkeep of gardens and landscapes for their amenity, cultural and recreational values (Adams *et al.*, 2008). For botanic gardens and arboreta there is an increased focus on 'conservation horticulture', described by Affolter (1997), to highlight the specialised knowledge and practical skills required in horticulture for the conservation of rare and threatened plants. A recent report by Botanic Gardens Conservation International (BGCI) described conservation horticulture as involving genetically diverse collections, potentially with plant material for eventual *in situ* conservation, and supporting conservation education and environmental sensitisation (Meyer *et al.*, 2024).

The experience of horticulturists varies widely, and the ways they plan, evaluate and share their results in cultivating plants for various purposes range from informal anecdotes to meticulously designed experiments. The sharing of knowledge and horticultural experience is a key activity, ensuring that lessons learned and research conducted may inform and improve practice, ultimately leading to improvements in the health of target plants and in production systems.

Horticultural knowledge and findings may be shared through various means, including industry magazines and scientific publications. Horticulturists may also share their findings through more informal methods. Such approaches include the telling of stories that convey local ecological knowledge (LEK), as well as highlighting certain observations, practices and perspectives of local communities regarding ecological relationships (Charnley *et al.*, 2007). An example of informal sharing of horticultural findings would be a farmer or grower telling a neighbour how their harvest

season turned out, and why they came to certain conclusions about their cultivation successes or failures.

According to the ASHS (2022), horticultural research can be categorised into three broad groups: discovery, development and evaluation. Discovery research, also called fundamental or basic research, is driven by a scientific question, rather than a specific problem to be solved. The main motivation is to expand knowledge and to develop information or ideas, with no prerequisite for creating a product/process or inventing something of social benefit. Development research is formulated to solve a specific problem, with the solution often based on applying knowledge derived from discovery research. The outcome of development research is pragmatic rather than academic, with an empirical goal of designing or developing new or improved methods, products, systems or technology. Evaluation or demonstration research is aimed at advancing progress made in research and development, with the goal of enhancing the efficiency of current practice, transferring capability or extending capacity. This type of work ideally seeks to compare the standard or status quo with alternatives or new developments. The results of such research are evidence-based and generally ready for direct application by practitioners and stakeholders. The categories of horticultural research defined by the ASHS provide some structure to conducting research; however, we suggest horticulturists may be further empowered by a research paradigm that more broadly recognises diverse approaches, including community-driven inquiries, experiential learning and participatory research models.

With conservation needs and climate change impacts continuing to increase,

and ongoing advances in technology, this study aimed to understand more about how horticultural research practitioners perceive horticultural research and excellence and how they and their institutions are involved, as well as to identify the most urgent needs of horticultural research among gardens and arboreta in the United States.

Methods and materials

Survey development

We developed a survey featuring 21 quantitative and qualitative questions (Supplementary materials, Table S1). Questions 1–7, 10, 11 and 13 focused on respondent profiles, covering location, name, age, horticultural involvement, years of experience, organisation, organisation size and the number of horticulturists in their organisation.

Questions 8 and 9 consisted of open-ended questions about the respondent's definition of horticultural research and excellence. Question 12 requested a selection of answers that represent the steps required to conduct successful horticultural research. Questions 14–16 explored which research categories are relevant at the respondent's facility, as well as what types of research are needed most in the coming years, and the barriers to conducting horticultural research. Questions 17–20 requested further information related to how often the respondent is involved in research, an example of a research project at the respondent's institution, which leading organisations conduct horticultural research and where the respondent looks to source horticultural research findings. Finally, the open-ended question 21 provided the opportunity for additional comments.

The open-ended questions were designed to gather in-depth and qualitative

information related to the respondents' knowledge, opinions and experiences regarding horticultural research, horticultural excellence and other important points not otherwise addressed in the survey. Question order was designed to mix multiple choice with open-ended questions as well as demographic prompts to reduce respondent fatigue and therefore ensure the maximum possible number of completed surveys. A privacy statement featured at the beginning of the survey. The online survey was developed using the cloud-based software SurveyMonkey Inc.⁶ This platform was chosen for its ability to track and synthesise survey data that would be relevant to this study. The survey was open for three months from 30 October 2023 to 30 January 2024.

Survey distribution strategy

Recognising the vast range in size, scope and form of horticultural operations in the United States, we believed that it was important for this study that sampling be conducted from members of multiple platforms and through various means of outreach. We also aimed to identify respondents who were professionally involved in horticulture. The method of distribution was through industry organisational fora including the American Public Gardens Association (APGA) and the ASHS, as well as through direct emails to registered US-based members of BGCI and the Interactive Community of Arboreta (ArbNet).

Data analysis

The privacy information related to name (Q3) and contact information was removed before analysis. Trends in the responses to the

open-ended questions on the respondent's definition of horticultural research (Q8) and excellence (Q9), and the examples of current research provided (Q18) were summarised using ChatGPT (OpenAI, 2024). We used OpenAI's ChatGPT-4 architecture as a tool for AI-assisted thematic synthesis. Responses to open-ended questions were input into the model in batches. ChatGPT was prompted to identify recurring patterns, concepts and sentiments across responses, and to group these into preliminary thematic categories. This AI-generated output was then reviewed by human researchers for accuracy, internal consistency and contextual alignment with the research objectives.

Standard statistical analyses were conducted using R (R Core Team, 2024) as implemented in RStudio (RStudio Team, 2020). The ggplot2 package was used for the construction of graphs (Wickham, 2016). Means (\pm SD) are presented. When two different treatments were compared, a Welch two-sample *t*-test was performed ($\alpha = 0.05$).

Results

Profile and representativeness of respondents (Q1, Q2, Q4, Q11, Q13, Q17)

We obtained a total of 128 responses across 116 organisations. The full dataset of all responses is provided in Supplementary Table S2 with personal and institutional information removed.

As a consequence of advertising through APGA and ASHS forums, the exact number of people contacted is unknown. An approximate response rate of 43% was calculated based on the number of responses received (128) and the number of email requests sent directly by the authors (300). We observed seven cases of responses from more than one individual in the same institution,

⁶ www.surveymonkey.com

which were kept in the dataset due to the low occurrence (four individuals from one institution in one case). Two respondents were not affiliated with an institution. Respondents represented 34 US states (Q1), including the District of Columbia. California had 11 respondents and Illinois 12. All other states had fewer than ten respondents (Fig. 1).

The survey had a 97% completion rate among those who participated, and took an average of 16 minutes to complete. None of the US territories (Guam, American Samoa, Puerto Rico and the Virgin Islands) responded to invitations to participate. Of the 128 respondents, 125 (98%) self-identified as being professionally involved in horticulture (Q2) and 3 stated that they were involved in horticulture but not professionally. The period of professional involvement with horticulture (Q11) ranged from 2 to 47 years with an average of 20 years ($SD \pm 12$). The age distribution of respondents (Q4) ranged from 26 to 76 years with an average of 47 years

($SD \pm 12$) showing no specific generational tendency. As would be expected, there is a positive correlation ($R = 0.79$) between the age of respondents and how long they have been involved in horticulture.

The three horticulture categories in which respondents most commonly participate (Q13, Fig. 2) are ‘other’ (56.3%), ‘ornamental crops’ (54.7%) and ‘plant ecology’ (44.5%). The ‘other’ category, elaborated in 72 individual comments (Supplementary materials, Table S2), encompasses diverse research areas such as arboriculture, urban forestry, rare plant conservation, plant health, invasive species management, seed science and landscaping. Several respondents also noted the interdisciplinary nature of horticulture.

The level of involvement in horticultural research reported by respondents (Q17) encompassed ‘not involved at all’ (16 respondents, 12.5%), ‘involved every few years’ (23 respondents, 18%), ‘periodically

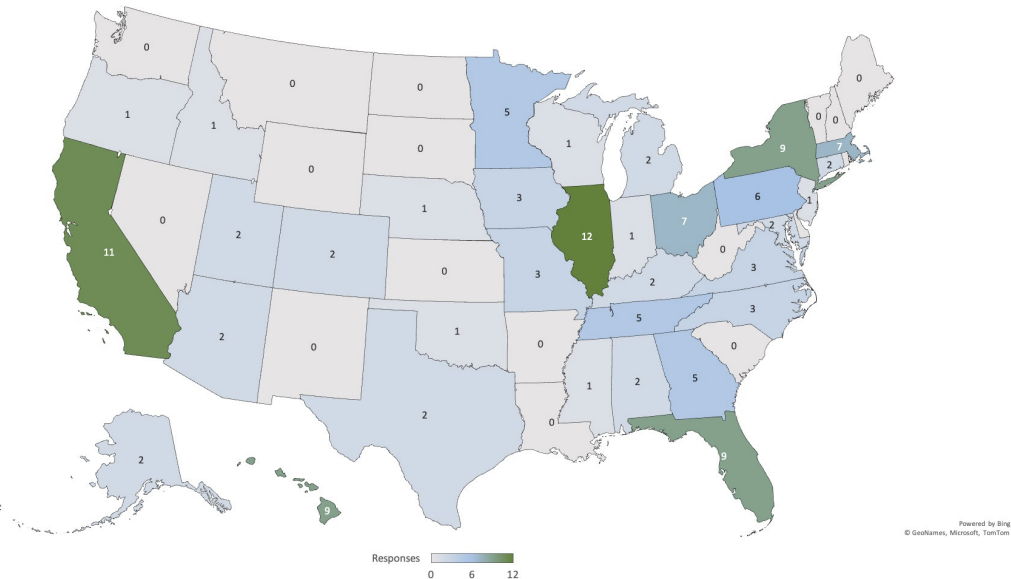


Fig. 1 Number of responses in the survey by US state. Darker shades (green) indicate higher response counts and lighter shades (blue/grey) indicate lower counts, or none at all (Q1).

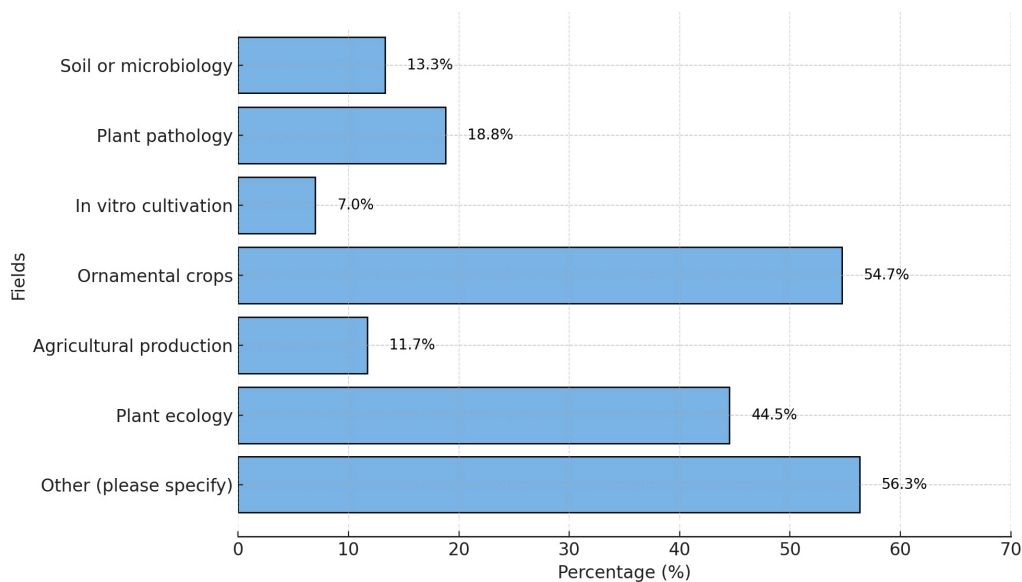


Fig. 2 Horticultural fields of involvement among respondent data (Q13). Figure created using RStudio (RStudio Team, 2020).

involved’ (66 respondents, 51.6%) and ‘heavily involved’ (23 respondents, 18.0%).

Profile of represented institutions (Q5–Q7, Q10)

The 116 institutions represented were a mixture of botanic gardens (43), arboreta (23), cemeteries (8), city (10) and university gardens (20), and other institutions (12) (Fig. 3). Some of the institutions self-identified as more than one of these categories (Q5), but we selected a single category for each respondent, based on their primary location. Other institutions included private estates, zoos and large green spaces, two examples being a conservatory and a retirement-community area.

The area managed by each institution (Q10) encompassed 0–10 acres (0–4.0 ha) (18% of respondents), 10–50 acres (4.0–20.2 ha) (21%), 50–100 acres (20.2–40.4 ha) (21%), 100–1,000 acres (40.4–404.7 ha) (33%) and more than 1,000 acres (404.7 ha) (8%). The total number of employees (Q7) per institution ranged from 2 to 7,000, with three universities

and one college institution reporting 7,000, 4,000, 3,000 and 1,200 total employees respectively. Excluding these four outliers, the number of total employees ranged from 2 to 600 (mean 264, SD ± 94.73). Approximately 60% of the respondents’ affiliations (76) had 50 or fewer employees.

The number of full-time horticultural staff (Q6) ranged from 0 to 100. A majority 94 (73%) of respondents were involved in horticultural operations with 20 or fewer people. Excluding the four outliers identified above and two individual university researchers not reporting staff numbers, the proportion of horticultural staff ranged from 1% to 65% of all employees (Fig. 4), and was positively correlated with the total number of employees ($R = 0.61$).

Defining horticultural research (Q8)

Six respondents skipped this question. The remaining responses were summarised using ChatGPT (OpenAI, 2024) prompted with: ‘I will now give you more than 100 answers to the

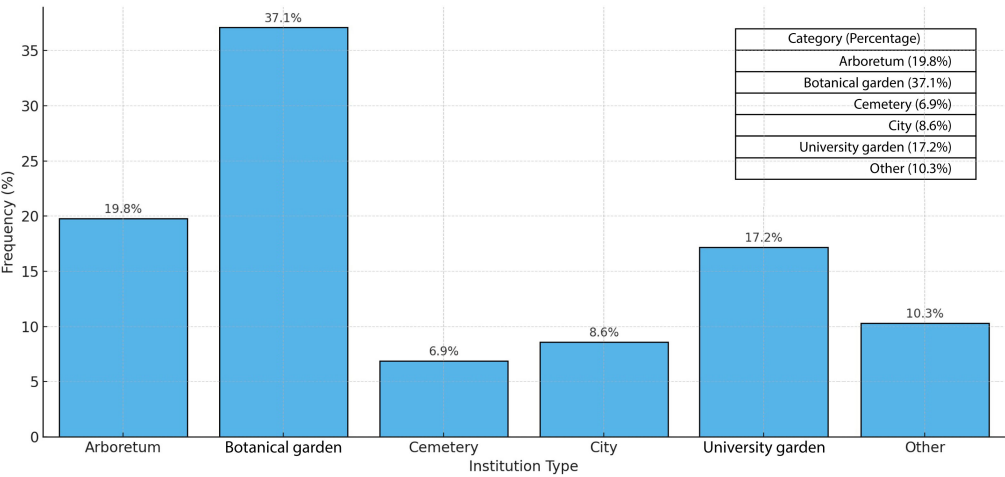


Fig. 3 Institutional categories participating in the survey (Q5). Figure created using RStudio (RStudio Team, 2020).

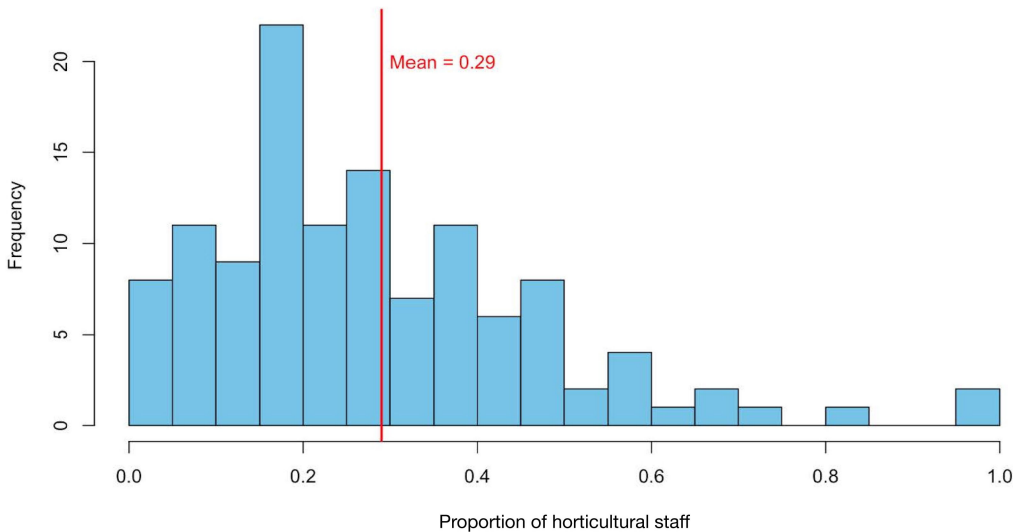


Fig. 4 Horticultural staff as a proportion of the institution's total number of employees. Figure created using RStudio (RStudio Team, 2020).

question: "Please define horticultural research in your own words". What are common trends in the answers I provided?"

From the survey responses provided, several common trends emerged (Fig. 5) (OpenAI, 2024). No modifications were made to the ChatGPT response.

1. **Scientific Inquiry:** Many responses emphasize the scientific nature of

horticultural research, highlighting the use of the scientific method, experimentation, data collection, and analysis to advance knowledge and understanding.

2. **Plant Cultivation and Care:** A predominant theme is the study of plant cultivation, propagation, and care. This includes aspects such as plant breeding, genetics, physiology, nutrition, and pest management.



Fig. 5 Bubble chart outlining the common trends of horticultural research as a result of synthesising open-ended responses.

3. **Environmental Interaction:** There's a focus on understanding how plants interact with their environment, including factors such as climate, soil conditions, and ecological dynamics. This encompasses research on plant adaptation, habitat suitability, and ecological restoration.
4. **Practical Application:** Several responses mention the practical application of research findings in horticulture, aiming to improve plant growth, productivity, and sustainability. This includes developing best practices for gardeners, growers, and land managers.
5. **Diverse Perspectives:** The responses reflect the diverse range of disciplines and approaches within horticultural research, including botany, ecology, genetics, agronomy, conservation biology, and landscape architecture.
6. **Collaboration and Outreach:** Many responses highlight collaboration with other disciplines, organizations, and stakeholders, as well as the importance of sharing research findings with the broader community through outreach, education, and extension programs.

'Overall, these common trends underscore the interdisciplinary nature of horticultural research and its importance in addressing global challenges related to food security, environmental conservation, and human well-being' (OpenAI, 2024).

Horticultural excellence

The responses were summarised using ChatGPT (OpenAI, 2024) prompted with: 'I will now give you more than 100 answers to the question: "How would you define horticultural excellence?" What are common trends in the answers I provided?'

From the survey responses provided, several common trends emerged (Fig. 6) (OpenAI, 2024). No modifications were made to the ChatGPT response.

1. **Holistic Approach:** Many responses emphasize the importance of considering various factors such as plant health, aesthetics, sustainability, and ecological function in horticultural practices. Horticultural excellence involves a comprehensive approach that integrates scientific knowledge with artistic design and environmental stewardship.
2. **Plant Diversity and Conservation:** There's a strong emphasis on the importance of preserving plant diversity, including rare and endangered species, and promoting conservation efforts. Horticultural excellence involves curating diverse plant collections and contributing to conservation initiatives.
3. **Education and Outreach:** Several responses highlight the role of education and outreach in horticultural excellence. Botanic gardens and horticultural institutions are seen as platforms for educating the public about plants, ecology, and conservation, thereby fostering greater appreciation and understanding of the natural world.
4. **Innovation and Research:** Horticultural excellence involves staying updated with the latest trends, technologies, and research findings in the field. It includes adopting innovative practices, conducting research, and sharing knowledge to advance the horticultural industry.
5. **Sustainability and Environmental Responsibility:** Many responses emphasize the importance of practicing



Fig. 6 Core components in defining horticultural excellence according to respondent data.

horticulture in a sustainable and environmentally responsible manner. This involves minimizing resource use, reducing environmental impact, and promoting practices that enhance ecosystem health and resilience.

6. Quality Plant Care and Management:

Horticultural excellence entails providing optimal care for plants to ensure their health, vitality, and aesthetic appeal. This includes proper plant selection, maintenance, propagation, and pest management, as well as meticulous record-keeping and documentation.

7. Community Engagement and Impact:

Horticultural excellence extends beyond plant care to positively impact communities and individuals. It involves creating spaces that inspire wonder and joy, fostering connections between people and plants, and contributing to the betterment of society through beautification, education, and environmental stewardship.

‘Overall, these common trends underscore the multifaceted nature of horticultural excellence, which encompasses not only technical proficiency but also a commitment to conservation, education, innovation, and community engagement.’ (OpenAI, 2024).

Model organisation conducting horticultural research (Q19)

The three most mentioned model organisations are Morton Arboretum (Illinois, 15 mentions), Missouri Botanical Garden (Missouri, 12 mentions) and Cornell University (New York, 10 mentions). A handful of other organisations mentioned at least five times were Mt. Cuba Center (Delaware),

Arnold Arboretum of Harvard University (Massachusetts) and the University of Florida (Florida). In total, 55 individual organisations were mentioned, possibly reflecting some degree of regional orientation. Twelve respondents mention more than one model organisation.

Steps required to conduct successful horticultural research (Q12)

All 128 respondents answered the question related to steps required to conduct horticultural research (Fig. 7). All categories of potential steps required were highlighted, with the least common response (73.4% of respondents) being ‘achieve necessary permit requirements’. One respondent commented that not all research requires explicit permits. Additional comments to the category ‘other’ were provided by 36 respondents (Supplementary materials, Table S2). One comment added ‘an understanding and evaluation of past research already done on the plants’. Several respondents added publication and open public sharing of data as additional required steps. Another commented that horticultural research also needs to consider human/plant interactions and connections. Some comments focused on the scientific method, as for example expressed by one respondent: ‘Design meaningful experiments, develop testable hypotheses, design studies that test those hypotheses, collect data, analyze data, draw conclusions from data.’

Horticultural research at responding organisations (Q14)

The three main categories of horticultural research being conducted at the respondents’ institutions (Q14, Fig. 8) are species and variety conservation (67.2%),

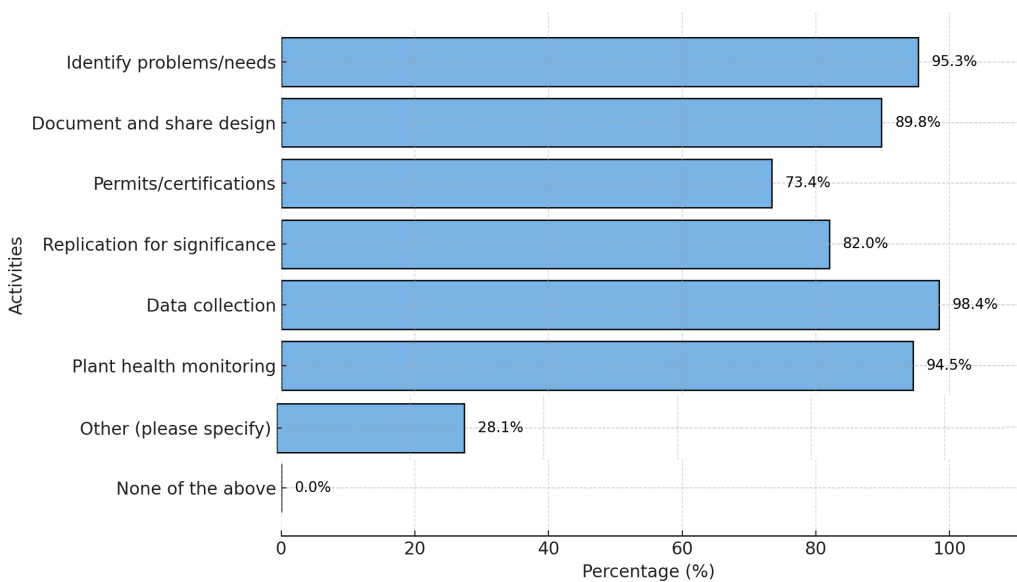


Fig. 7 Steps required to conduct successful horticultural research according to survey respondents. Figure created using RStudio (RStudio Team, 2020).

propagation (65.6%) and landscape design (56.3%), followed by pests and diseases (47.7%). Nine of the respondents commented (Supplementary materials, Table S2) that no research was currently being conducted. Other respondents provided additional comments on their institution's research focus including severe weather and climate change management, native plants, biocultural conservation, historical landscapes, heirloom varieties, hardiness and ornamental potential, urban forestry and pollinator interactions.

Examples of horticultural research

The responses were summarised using ChatGPT (OpenAI, 2024) prompted with: 'I will now give you more than 100 answers to the question: "Provide an example of a horticultural research project happening at your institution." What are common themes in the answers I provided?' From the survey responses provided, several common trends

emerged (OpenAI, 2024). No modifications were made to the ChatGPT response.

1. **Plant Health and Growth:** Many projects involve tracking plant health, growth rates, and responses to various treatments or environmental conditions.
2. **Propagation and Cultivation:** Several projects focus on propagation methods, including seed propagation, asexual propagation, and developing protocols for rare or endangered species.
3. **Biodiversity Conservation:** There is a significant emphasis on conservation efforts, including studying rare and endangered species, reintroducing native species, and assessing the impact of invasive species on ecosystems.
4. **Pest and Disease Management:** Research on controlling pests and diseases, including monitoring, identifying pathogens, and testing control methods.

- 5. **Climate Resilience:** Some projects aim to improve plant resilience to climate change, including drought tolerance screening, selecting species suitable for managed landscapes, and studying phenology in response to climate variations.
- 6. **Collaboration and Partnerships:** Many institutions collaborate with universities, governmental agencies, and other organizations for research projects, indicating a strong network within the horticultural research community.
- 7. **Urban Agriculture and Restoration:** Several projects focus on urban greening, such as urban forest planning, green space management, and restoration of native habitats in urban areas.
- 8. **Cultivar Trials and Plant Breeding:** Research on developing new cultivars, improving existing ones, and evaluating plant performance under different conditions.
- 9. **Data Collection and Monitoring:** Projects involve data collection on

plant–pollinator interactions, phenology, disease progression, and other aspects relevant to horticulture and ecology.

- 10. **Education and Outreach:** Some institutions engage in citizen science projects or provide resources for educational purposes, involving students and the public in research efforts.

Future needs of horticultural research (Q15)

When asked to rank the future importance of the same research categories (Q15, Fig. 9), the primary research category was still species and variety conservation which, when compared to results related to research currently happening at respondent facilities (Q14, Fig. 8), increased from 67.2% to 75.0%. The second and third most important future research categories were pests and diseases (which increased from 47.7% to 68.8%) and plant ecology (which increased from 40.8% to 50.8%). Propagation decreased to 26.6% from 65.6%, and landscape design decreased to 18.8% from 56.3%. In addition,

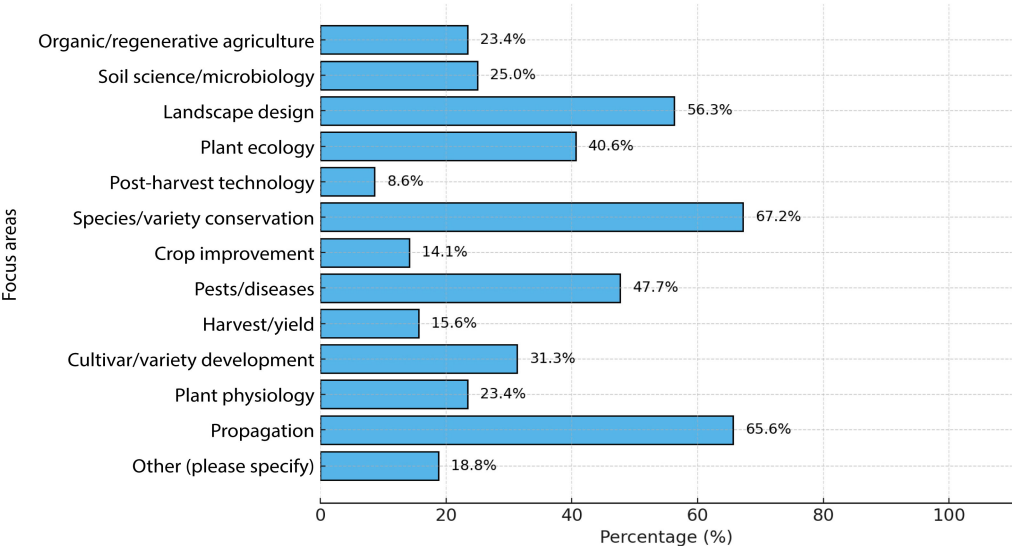


Fig. 8 Horticultural research focus areas among survey respondents. Figure created using RStudio (RStudio Team, 2020).

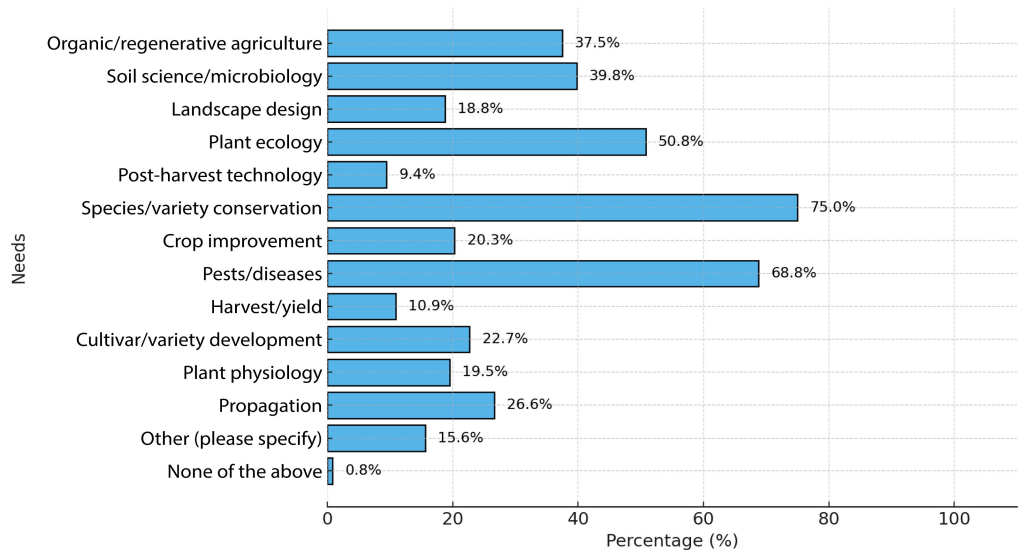


Fig. 9 Future need categories of horticultural research according to survey respondents. Figure created using RStudio (RStudio Team, 2020).

20 respondents (15.6%) provided detailed comments (Supplementary materials, Table S2), which primarily focused on climate resilience and adaptation, followed by native and rare and endangered plant conservation.

Major challenges to conducting horticultural research (Q16)

The three major barriers to conducting horticultural research (Q16, Fig. 10) selected from the predetermined options were ‘insufficient funding’ (78.9%), ‘personnel shortages’ (62.5%) and ‘institutional priorities’ (53.9%). Only one respondent did not select any of the presented categories (selection of ‘none of the above’). Twenty respondents (10.2%) selected and listed ‘other’ (Supplementary materials, Table S2), several of which expanded on the options ‘insufficient funding’ and ‘personnel shortages’. Others highlighted a lack of incentives for collaborating with other disciplines (such as soil science, plant

pathology, entomology, botany, engineering, artificial intelligence or robotics), lack of access to training (for example, in botany and horticulture), and lack of adequate and open access to research. One mentioned regulation on the free flow of germplasm.

Preferred sources of horticultural research findings (Q21)

The three main sources used to search for horticultural research findings (Q21, Fig. 11) are databases (33.6%), other sources (29.7%) and personal communication (17.2%). Relatively few respondents would search in magazines (12.5%) or handbooks (3.1%). In addition, 38 respondents provided comments when selecting the category ‘other’ (Supplementary materials, Table S2). Comments included professional societies including websites and conferences (such as APGA and BGCI), and university extension services. Eighteen respondents specifically mentioned scientific journals

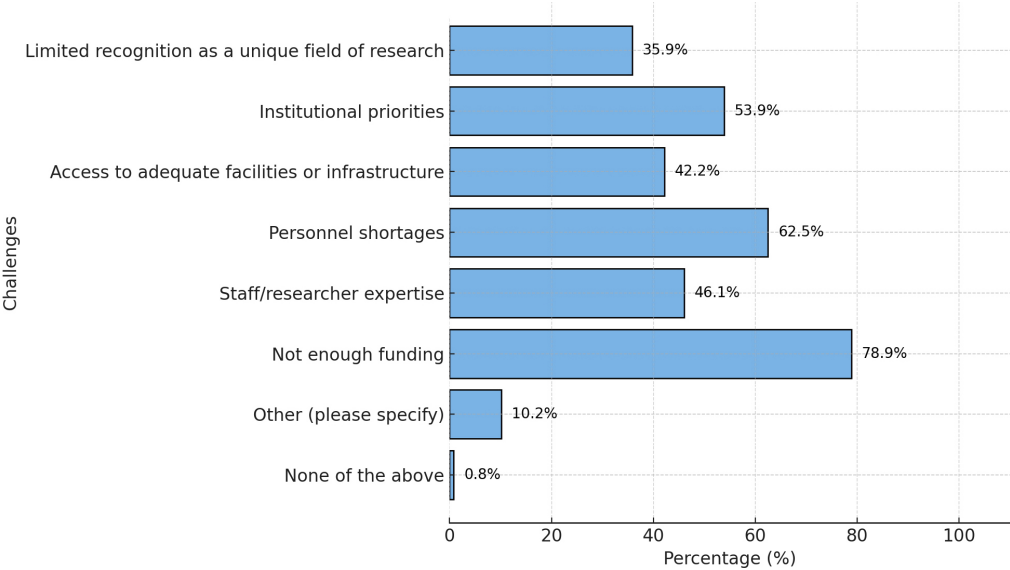


Fig. 10 Major challenges and barriers to conducting horticultural research according to survey respondents. Figure created using RStudio (RStudio Team, 2020).

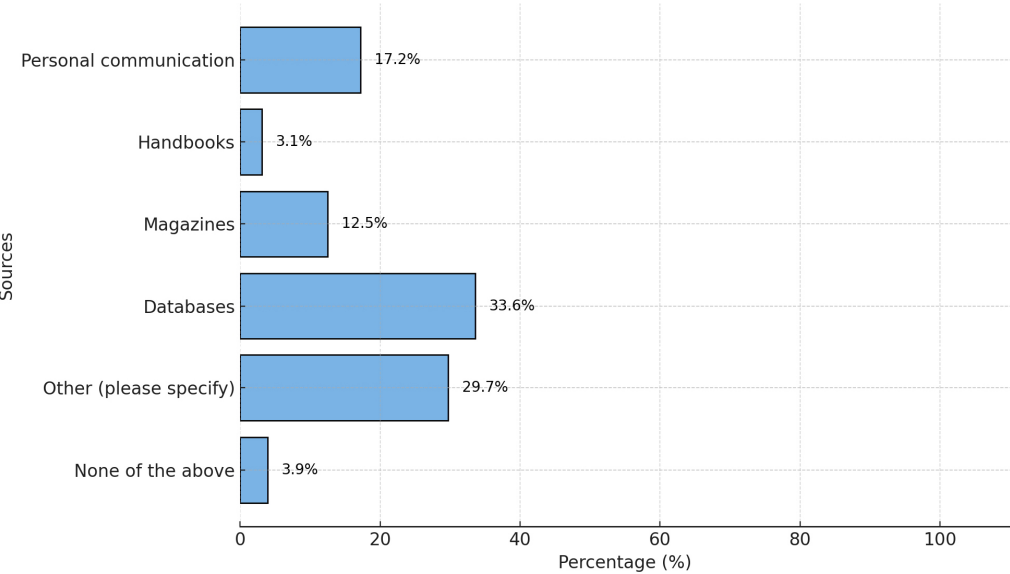


Fig. 11 Preferred sources of horticultural research findings among survey respondents. Figure created using RStudio (RStudio Team, 2020).

including Google Scholar. One comment mentioned the fact that primary research needed by practitioners is often behind a paywall. Another respondent was interested in information about specific journals considered useful by peers.

Additional comments provided by respondents (Q21)
Seventeen respondents provided additional comments in the final comment option (Q21, Supplementary materials, Table S2). Some mentioned horticultural research being

under-recognised, and a general lack of resources such as funding and infrastructure, shortage of qualified staff and closure of horticulture degree programmes. One suggested that mentoring programmes for young horticulturists would be helpful. Scientific literature paywalls were mentioned as prohibiting practitioners' access to primary research. Some responses mentioned the need for more collaboration and less job-description siloing among horticulturists, arborists and researchers. One respondent called for a broader definition of research to more widely acknowledge the value of practitioner-based research in botanic gardens, which is often not designed to be replicable, but is valuable and shareable.

Discussion

Current status of horticultural research among US botanic gardens and arboreta

The majority of responses were obtained through the targeted emails to BGCI and ArbNet members, who typically represent industry leaders and organisations striving for best practice and professional recognition. The high survey response rate of 43% and completion rate of 97% shows a general interest in and need for horticultural research among botanic gardens and arboreta across the United States (Supplementary materials, Table S2). An average of 30% of the total staff within these organisations work in the area of horticulture. The level of involvement in horticultural research varied considerably from about 30% not being involved or being involved every few years to about 70% being involved periodically or heavily. Lack of funding and insufficient staff and time were considered the main challenges to conducting horticultural research. Nevertheless, it is undeniable that a

considerable amount of informal research is taking place.

As one respondent stated: 'While we are not conducting formal research at this time, many of these things are happening experimentally/informally.' Another respondent commented: 'I believe there is a wealth of knowledge locked up with experienced horticulturists that is often lost due to both documentation not being part of their job and the siloing that tends to develop between horticulturists and research scientists.' This comment suggests that we should revise the way we think about botanic garden horticultural research, from seeing it as a narrow field based on propagation to understanding it more broadly as including ecology, people and traditions.

Future horticultural research needs among US botanic gardens and arboreta

Based on themes expressed in responses to the survey, research focus among respondents (Q13–Q15) is changing from a narrower focus on propagation and individual plant health towards a more holistic approach. This comprises an understanding that plants are not growing in isolation but are part of greater ecological systems including people. While the primary focus of horticultural research continues to be on species and variety conservation, future research needs to address increasing pressure from pests, diseases and climate change. Encouraging openly accessible publication and the sharing of results with practitioners is considered important and will require institutional support for dissemination time, as well as funding or other solutions to the problem of paywalls, which may be prohibitive for practitioners who do not have access to university libraries (Tennant *et al.*,

2016). More informal sharing of knowledge through practical work, networks and community conferences will also continue to be important (BGCI, 2023).

A new framework for horticultural research

One recurring theme among respondents was the need to bridge informal and formal knowledge generation and sharing. As one respondent expressed it: 'I'd be interested in a broader definition of research to more widely acknowledge the value of practitioner-based research in botanic gardens. It is often not designed to be replicable, but is valuable and shareable. Could there be a standard created for practitioner-based research that is less rigorous than the standard for typical published research? Practitioner knowledge falls somewhere between Western ideas of science and TEK (traditional ecological knowledge). Valuable but rarely captured and communicated well.'

To develop a new framework to delineate the difference between the two general approaches to horticultural research, we took inspiration from the thinking of Eraut

(1994), whose work provides a foundational outline for the development of professional knowledge and competence. Within this important reference for the development of professional workers, Eraut (1994) provides a distinction between formal (technical) and informal (practical) learning and knowledge (Appendix 1).

Considering these two overarching methods of increasing knowledge, which is the essence of conducting research, we propose a general categorisation of horticultural research into the following two approaches (Table 1):

- 1. **Technical horticultural research** – horticultural research that largely aligns with the processes of hypothesis-driven, analytical and reductionist methods.
- 2. **Practical horticultural research** – horticultural research that focuses on experience, intuition and ongoing practice-based methodology.

Both the proposed technical and practical horticultural research processes require a progressive sequence of events (Figs 12 and 13). Some of the research steps are shared

Technical horticultural research	Practical horticultural research
<div>1. Identify a need for horticultural improvement</div> <div>2. Identify research objectives</div> <div>3. Literature review</div> <div>4. Environmental and ethical considerations</div> <div>5. Research proposal</div> <div>6. Budget and funding</div> <div>7. Experimental design</div> <div>8. Data collection and analysis</div> <div>9. Reporting and documentation</div> <div>10. Peer review</div> <div>11. Publication and presentation</div> <div>12. Data sharing</div>	<div>1. Identify a need for horticultural improvement</div> <div>2. Identify research objectives</div> <div>3. Environmental and ethical considerations</div> <div>4. Data collection and analysis</div> <div>5. Reporting</div> <div>6. Data sharing</div>

Table 1 Comparison of typical steps in technical and practical horticultural research.

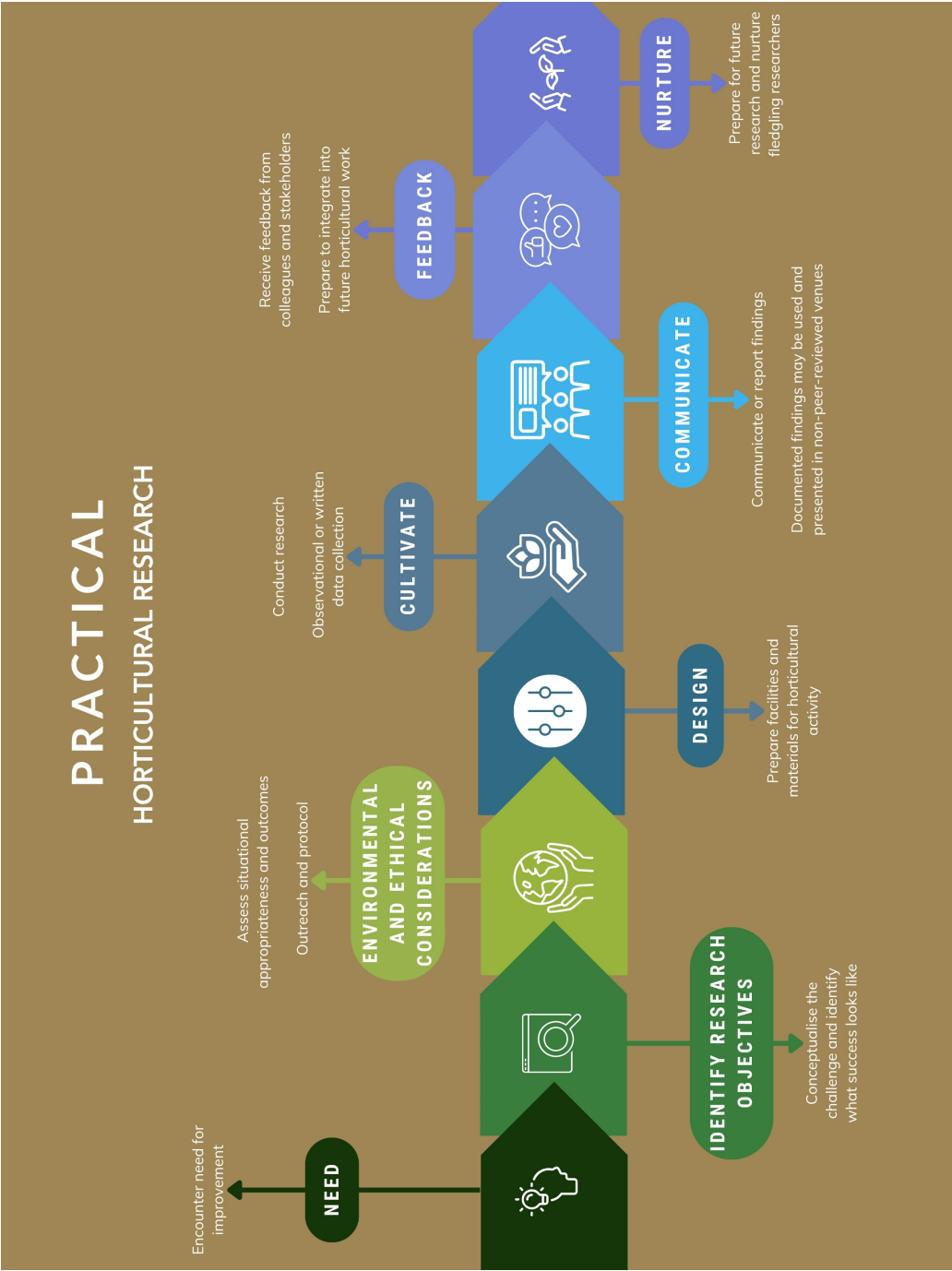


Fig. 12 Practical horticultural research pathway flow chart.

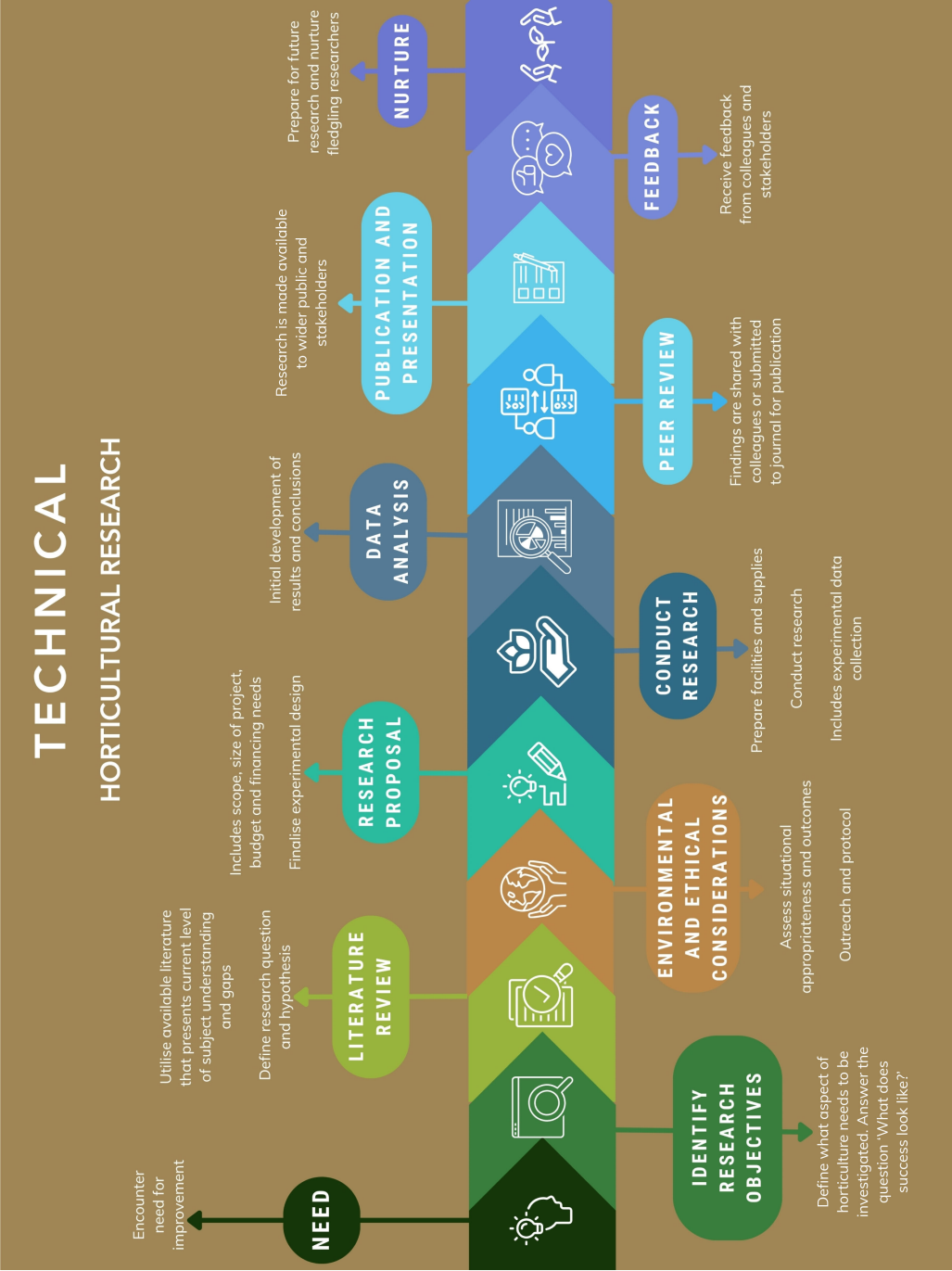


Fig. 13 Technical horticultural research pathway flow chart.

by both approaches with each requiring to identify a need for horticultural improvement; to identify research objectives; environmental and ethical considerations; data collection and analysis; some level of reporting information; and data sharing.

Horticultural research practitioners may employ this framework by evaluating both approaches consciously, considering what would be best for the goals of their research. While both the practical and technical approaches allow for innovation and new findings, resources, time and the cultural context of the research environment all influence methodology. Additional details and visualisation of both practical and technical approaches to horticultural research are shown in Figs 12 and 13 respectively. The technical research pathway more closely aligns with the existing research categories identified by the ASHS (2022). Horticulturists may use tools such as rubrics, rating scales or qualitative assessments to evaluate key factors in selecting approaches for horticultural research. These tools can also help assess progress towards horticultural excellence.

Concluding remarks

This research offers insight into various components of the field of horticultural research and excellence in the United States provided by a wide range of representatives associated with APGA, the ASHS, BGCI and ArbNet. We found that the trends identified when defining horticultural excellence are largely interdependent, supporting each other to result in more sustainable, diverse and engaged horticultural landscapes.

Analysis of the survey data has enabled us to propose a new framework for horticultural research that delineates technical or practical approaches. Ultimately, this work supports the horticultural researcher's ability to better

understand the make-up and direction of the field as well as to employ new tools for the professional development and execution of projects.

Supplementary materials online

The following supplementary materials are available on the online publication homepage: **Table S1**: Survey questions and privacy statement; **Table S2**: Raw data responses to the survey, excluding privacy information.

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Author contributions

MO developed the idea and designed the study with NR. JA, SB and DR helped design the questionnaire. MO developed the technical and practical horticultural research pathways and figures. MO drafted the manuscript with NR. All authors contributed to revising the manuscript before submission.

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Appendix 1 Comparison of technical and practical knowledge

The following description of technical knowledge is reproduced from Edmonstone (2011), adapted from Eraut (1994):

- Typically codified and written
- Based on established practice
- In accordance with prescription
- Used in clearly defined circumstances
- To meet an envisaged and familiar result
- Emphasis on routine (method, analysis, planning)
- Focus on well-defined ('tame') problems.

The following description of practical knowledge is reproduced from Edmonstone (2011), adapted from Eraut (1994):

- Typically expressed in practice and learned only through experience
- Based on established practice modified by idiosyncratic technique
- Loosely, variably, uniquely in a discretionary way based on personal insight
- Used in both expected and unexpected circumstances
- To meet an indefinite or novel result
- Emphasis on non-routine (variety, invention, responsiveness)
- Focus on poorly defined ('wicked') problems.