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# Exploring the Adoption of High Tunnel System among Specialty Crop Growers: Perceptions, Use Experiences, Willingness to Pay, and Influencing Factors

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***Abstract.*** **High tunnels are a low-cost protected crop production system and can help mitigate specialty crop production risks from extreme weather, diseases, and pests. Understanding growers' perspectives is essential in promoting the adoption of high tunnels. This study examined specialty crop growers' perceptions, experiences, and willingness to adopt high tunnels in Florida. Our results indicate that both high tunnel users and nonusers have positive perceptions of high tunnels for crop production. Most high tunnel users grow multiple crops in the same season and use in-ground soil systems for crop production in high tunnels. While growers' willingness to pay for high tunnels is not likely to be affected by most factors included in the analysis, their actual adoption behavior is positively correlated with their awareness of the US Department of Agriculture–Natural Resources Conservation Service high tunnel financial assistance program, land being owned by growers as a corporation, and race (e.g., white) but negatively correlated with their farm size. These findings provide crucial insights for researchers to develop targeted research agendas to address key challenges growers face in high tunnel specialty crop production. The results can also guide policymakers, extension services, and industry stakeholders in promoting high tunnel use by effectively implementing policies and programs to assist with high tunnel adoption.**

Specialty crop production plays a critical role in local and regional food systems in the United States, accounting for 29% of local food farms and generating 51% of local food sales in the United States (Low et al. 2015). It not only provides essential nutrition and variety in the US diet (Story et al. 2008) but also supports regional economies by fostering local job creation, reducing food miles, and enhancing food security (Low et al. 2015). However, specialty crop growers face numerous challenges, including production risks from extreme weather, diseases, weed competition, pest infestations, and other factors (Chen and McCarl 2009; Collier et al. 2008). Developing effective crop production risk mitigation strategies is crucial to the sustainability of the specialty crop industry and the broader US food system.

Protected production systems such as high tunnels offer a promising solution to the production challenges faced by specialty crop growers. The high tunnel is usually a low-cost, plastic-covered, and passive solar-heated structure to create a protected crop production system (Carey et al. 2009). Previous studies have shown that high tunnels could benefit crop production in multiple aspects. It can reduce the crop damage caused by extreme weather events (Carey et al. 2009), extend crop production seasons (Belasco et al. 2013; Bruce et al. 2019; Carey et al. 2009), and allow growers to access the early- or late-harvest season market to receive price premiums for the crops (Belasco et al. 2013; Nian et al. 2022). In addition, the moderately protected environment can help improve crop quality and yield through improved microclimate, water, disease, and nutrient management (Frey et al. 2020; O'Connell et al. 2012). To encourage the use of high tunnels, the US Department of Agriculture–Natural Resources Conservation Service (USDA-NRCS) established a High Tunnel Initiative, a financial assistance program to assist growers in installing a high tunnel in their farm operations (USDA-NRCS 2023). Initially piloted in 2009, the program became available in all states in 2014. Currently, the NRCS local offices throughout the United States and territories administer the program and work closely with growers to help them apply for it (Donovan et al. 2023).

Although research trials have demonstrated great promise in using high tunnels to improve crop production (Belasco et al. 2013; Conner et al. 2010; Palonen et al. 2017) and although policy support is available, there is limited insight into specialty crop growers' perspectives on using high tunnels, particularly in the southern United States. A few studies have documented growers' perspectives and challenges of using high tunnels for crop production in the Midwest of the United States using case studies (Bruce et al. 2019, 2021; Conner and Demchak 2018), but the benefits of using high tunnels could vary by region and farm operation. For example, warmer weather in the southern United States may reduce the season-extension benefits of high tunnels normally seen in northern regions. Bruce et al. (2021) found that growers operating different types of farms took distinct approaches to managing high tunnel crop production on their farms, suggesting that growers' use of high tunnels can vary by farm operation. Limited studies have examined growers' high tunnel adoption decisions and the use of high tunnels in crop production in the southern United States.

To fill the knowledge gap in the literature, this study provided a picture of specialty crop growers' attitudes and use of high tunnels in Florida, a leading specialty crop production state in the United States. Using specialty crop grower survey data, we first examined growers' perceptions of high tunnels. We also compared the perceptions between growers who used high tunnels and those who did not through a $\chi^2$ statistical test. Understanding growers' perceptions can reveal both the challenges and benefits associated with high tunnel crop production of specialty crops. The information can help researchers develop research agendas to better address the critical issues faced by growers who have used or are interested in using high tunnels.

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Second, we explored growers' crop production practices in high tunnels using descriptive statistical analysis. It can provide information on the types of high tunnels growers typically use, how long they have used them, and what production practices they use to produce crops in high tunnels. This knowledge can serve as a current assessment of high tunnel use that policymakers and researchers can reference when developing programs and research agendas to promote high tunnel crop production in the United States.

Last, we identified farm attributes and other factors associated with growers' high tunnel adoption decisions. Specifically, we employed regression analysis to identify specific factors correlated with growers' decisions to adopt high tunnels. We examined both growers' current adoption behaviors and willingness to pay (WTP) for high tunnels. The findings of this analysis may help various specialty crop sector stakeholders, such as policymakers, extension services, and industries, to develop policies, outreach programs, and marketing strategies to promote high tunnel adoption among specialty crop growers more effectively.

## Materials and Methods

*Survey development and distribution.* We developed a specialty crop grower survey to understand their perspectives, attitudes, experiences, and decisions to adopt high tunnels. When creating the survey instruments, we followed a multistage process to ensure comprehensive coverage of high tunnel adoption issues and maximize response validity. First, we conducted an extensive literature review of high tunnel crop production to identify key benefits and challenges documented in previous studies. Then, we synthesized the findings to develop the initial survey instrument. Next, we interviewed extension specialists and plant science researchers with experience in high tunnel production and obtained feedback on the technical accuracy and relevance of the survey instruments. We refined our questions based on their recommendations. After that, we conducted in-depth interviews with specialty crop growers experienced in high tunnel production. In the interview, we asked them to evaluate question clarity and assess survey flow and completion time. Last, we modified the language and structure of the survey instruments.

At the end, we included four sections in the survey. In the first section, we asked about growers' perceptions of high tunnels. Growers use a five-point Likert scale to indicate how much they agree/disagree with each statement about high tunnels. In the second section, we asked growers to answer questions regarding whether they have adopted high tunnels and how much they would like to pay to build new high tunnels. In the third section, we collected information on growers' crop production experiences in high tunnels. Only high tunnel users are allowed to answer this part of the survey. The information includes the style of high tunnels the growers use, how long they have been using them, and what management practices they have used for high tunnel crop production. In the last section, we collected growers' farm characteristics and demographic information, including their farm size, farm sale channels, age, education, gender, race, years of farming experience, etc. The survey is estimated to take 15 to 20 min to complete.

Upon approval by the Institutional Review Board of the University of Florida (IRB202101236), we distributed the survey among Florida specialty crop growers using a mixed method following Dillman et al. (2014). The online version of the survey was distributed through Qualtrics using the specialty crop growers' e-mail addresses collected from agricultural marketing companies, the USDA organic agricultural database, and extension specialists. Growers interested in participating could access the survey by clicking the link in the e-mail. Meanwhile, the paper version of the survey was distributed by mail to addresses collected from face-to-face recruitment at multiple extension events and farmers markets in Florida. In the cover letter accompanying the mail survey, we informed growers about the online version, requesting those who had already completed the survey online to disregard the paper version. After collecting the responses from both online and mail, we manually cross-checked the data to ensure that no growers completed both the online and mail versions.

*Statistical analysis.* We used descriptive statistics to summarize survey responses and performed statistical analysis to fulfill research objectives. All data analysis was conducted using statistical packages in the R 4.2.3 environment (R, https://www.r-project.org/). To explore growers' perceptions of high tunnels in various aspects, we asked growers to indicate to what extent they agreed/disagreed with a series of statements relating to high tunnel crop production in the survey. The statements include crop production practices under high tunnels; the economic, environmental, and horticultural benefits of high tunnels; and the importance of high tunnels for farm business success. We measured growers' perspectives using a five-point Likert scale, where 1 indicates strongly disagree with the statement and 5 indicates strongly agree with the statement. In addition, we tested whether high tunnel users and nonusers have different perceptions using the $\chi^2$ test, a common test used to examine whether two categorical variables' distributions are independent (Sirkin 2006).

We conducted a descriptive statistical analysis to investigate crop production practices employed by current high tunnel users. Specifically, we made histograms to show the types of high tunnels growers use, how long they have been using them, whether they conduct multicropping in high tunnels, and what cultivation system they use for high tunnel crop production.

We used multivariate regression analysis to investigate whether and to what extent growers' decisions to adopt high tunnels are correlated with their farm characteristics and other factors. We included two dependent variables in the analysis: growers' use of high tunnels and WTP for high tunnels. We measured growers' use of high tunnels based on the question, "Are you using high tunnels in crop production?" where 1 indicates yes and 2 indicates no. We measured growers' WTP for high tunnels using an open-ended contingent valuation method, a commonly used approach for valuing market and nonmarket goods, including new technologies (Olum et al. 2020; Shi et al. 2014) and environmental goods (Amigues et al. 2002). In the survey, respondents were asked: "How much are you willing to pay for high tunnels ($/square foot)?" We chose the open-ended contingent valuation method to elicit growers' WTP, because it is easier to implement in a paper-based survey than other approaches, such as the single- or double-bounded contingent valuation methods, which require randomization of starting values to minimize starting point bias. Additionally, this method can avoid the potential bias associated with the payment card approach, where the predefined range of options may constrain respondents' answers and influence the values they report (Johnston et al. 2017; Shi et al. 2014). To mitigate potential hypothetical bias of the contingent valuation questions, at the beginning of the survey, we informed respondents that there are no right or wrong answers to the survey questions, and it is important for them to provide honest answers to the survey questions. We also included a cheap talk script before the contingent valuation questions, as previous

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studies have shown this approach to be effective in mitigating hypothetical bias in stated preference elicitation (Lusk 2003).

The first category of explanatory variables used to explain growers' high tunnel adoption decision measures growers' knowledge of state and federal programs to support growers' use of high tunnels. The first variable is a dummy variable indicating whether a grower knows where they can get support when encountering issues related to high tunnel crop production. Previous studies have shown that despite the potential benefits of high tunnels, high tunnel production requires specialized knowledge and experience for successful implementation (Conner et al. 2010; Janke et al. 2017; Waldman et al. 2012). We propose that a grower's awareness of existing programs that provide supporting information for high tunnel crop production may affect their adoption decision. The second variable is a dummy variable indicating whether a grower is aware of the USDA-NRCS financial assistance programs targeting high tunnel production systems. The USDA launched the High Tunnel Initiative through the NRCS in 2009 to provide financial assistance for growers to install high tunnels (Donovan et al. 2023; USDA-NRCS 2023). The programs have supported the construction of more than 13,000 high tunnels in the United States (Bruce et al. 2019). Therefore, being aware of the USDA-NRCS programs may affect growers' decisions to use high tunnels.

The second category of explanatory variables captures growers' perceptions of high tunnels. We calculated the average responses to a series of five-point Likert scale questions focusing on various aspects of the high tunnel crop production to measure these perceptions. The first perception category focuses on production outcomes. Specifically, respondents were asked about their thoughts on the impact of high tunnels on crop yield and quality, the ability to extend the growing season, the potential to reduce crop losses caused by severe weather, and whether high tunnels are essential for maintaining farm profitability and competitiveness in the coming years. The second category addresses perceptions related to crop and resource management. This includes whether growers believe high tunnels can improve soil quality, enhance nutrient use efficiency, increase air quality, and reduce energy use by enabling local food supply and minimizing transportation needs.

The third category of explanatory variables includes farm characteristics such as land ownership, farm size, farm sale values of the entire farming operation, and whether growers sell crops through direct-to-consumer channels. Previous studies have indicated that farm characteristics can significantly affect growers' adoption of new technologies. For example, Nian et al. (2020) found that growers with large farm sizes were more likely to adopt water-saving irrigation technologies because they tended to have more capital to invest in technologies. For high tunnel adoption, Bruce et al. (2021) found that farm operations with different marketing strategies and farm sizes could be associated with divergent levels of financial returns from high tunnel crop production. As a result, they might take distinct approaches to integrate high tunnels on their farms.

The last category of explanatory variables includes growers' sociodemographic characteristics: gender, race, whether they are Hispanic or not, education level, and farming experience. Previous studies have indicated that growers' demographic characteristics could affect their adoption of new technologies. For example, Muriithi et al. (2018) identified that gender could significantly explain growers' adoption of new technologies worldwide. Studies such as Nian et al. (2020) showed that growers with higher education levels were more likely to adopt new technologies because more-educated growers can more easily grasp the technical know-how of new technologies. Koundouri et al. (2006) and Olen et al. (2016) revealed that growers with more farming experience were more likely to adopt new production systems because they had more knowledge on how to adapt their crop production to a new production system.

Because the dependent variable indicating whether growers use high tunnels is a binary variable, we used a probit regression model to examine whether and to what extent the explanatory variables correlate with the growers' use of high tunnels. Previous studies, such as those by Koundouri et al. (2006) and Nian et al. (2020), have used probit regression to investigate factors correlated to growers' decisions to adopt agricultural technologies. When analyzing growers' WTP for high tunnels, we used a linear regression model to examine the correlations between the explanatory and dependent variables because the dependent variable (i.e., growers' WTP for high tunnels) is continuous. In addition, as noted by Olum et al. (2020) in a systematic review of WTP studies for agricultural technologies, multiple studies that employed the open-ended contingent valuation method to elicit growers' WTP for innovations have used linear regression models to identify factors associated with growers' WTP.

## Results and Discussion

*Summary of statistics.* After collecting survey responses, we included responses that had completed the entire survey in the analysis. In the end, a total of 62 valid responses were included in the final data analysis. Table 1 shows the summary statistics of respondents' farm and sociodemographic characteristics in our sample and their comparison with the 2022 USDA Census of Agriculture for Florida. Around 55% of the respondents in our sample are females. Our sample includes more females than the state, as the 2022 USDA Census of Agriculture for Florida indicates. However, it is consistent with other

Table 1. Summary statistics of respondents' farm and demographic characteristics.

| Variable | Florida farm characteristics from 2022 USDA Census of Agriculture | Sample | *SD* | Min | Max |
|---|---|---|---|---|---|
| Demographics | | | | | |
| Female (%) | 41 | 55 | ND | ND | ND |
| Hispanic (%) | ND | 8 | ND | ND | ND |
| White (%) | 94 | 53 | ND | ND | ND |
| Education – college (%) | ND | 61 | ND | ND | ND |
| Education – graduate (%) | ND | 24 | ND | ND | ND |
| Farm characteristics | | | | | |
| Land ownership – corporate | ND | 18 | ND | ND | ND |
| Farm size (ha) | 87 | 34 | 93 | 0.2 | 455.27 |
| Farm sales value ($1000) | 229 | 166 | 345 | 0.25 | 1250 |
| Farm experiences (years) | 18 | 14 | 11 | 1.0 | 32 |
| Direct to consumers (%) | 6.6 | 18 | ND | ND | ND |
| High tunnels | | | | | |
| High tunnel use (%) | ND | 48 | ND | ND | ND |
| Willingness to pay for high tunnels ($/square meter) | ND | 49.62 | 31.91 | 0.00 | 107.64 |
| Aware source of high tunnel information (%) | ND | 23 | ND | ND | ND |
| Aware of USDA-NRCS financial assistance program (%) | ND | 53 | ND | ND | ND |
| Observations | | 62 | | | |

Max = maximum; Min = minimum; ND = no data; NRCS = Natural Resources Conservation Service; *SD* = standard deviation; USDA = US Department of Agriculture.



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studies using the US agricultural growers' sample, such as Rigotti et al. (2023), in which a large proportion of the female participants was reported. Around 53% of the respondents in our sample are white, which is less than the state average (94%). In addition, 8% of the respondents in our sample are Hispanic. Collectively, respondents in our sample have a high level of education: 61% have attended college, and 24% have attended graduate school.

Regarding farm characteristics, 18% of the respondents own farmland as a corporation. The average farm size in our sample is nearly 34 ha (i.e., 85 acres), which is smaller than the state average (87 ha, or 217 acres) according to the 2022 USDA Census of Agriculture. The potential explanation for the difference is that our sample only focuses on specialty crop growers in Florida, while the 2022 USDA Census of Agriculture includes all kinds of agricultural growers in Florida (USDA 2023). The average grower's farm sale value in the present study is about $165,950 per year, which is lower than the state average ($228,720 per year). The respondents in our sample have an average of 14 years of farming experience. Nearly 18% of the respondents in our sample have sold their crops through the direct-to-consumer market channel, which is higher than the state average (6.6%).

In addition, 48% of the respondents in our sample adopted high tunnels at the time of the survey. Respondents, regardless of whether they have adopted high tunnels, are willing to pay $46.93 per square meter (i.e., $4.36 per square foot) on average for high tunnels (Table 1). According to Nian et al. (2023), the estimated construction cost of multibay high tunnels with an automation system for ventilation—a high-end high tunnel type—in Florida ranges from $66.31 to $72.33 per square meter (i.e., $6.16 to $6.72 per square foot), which is much higher than the average amount respondents are willing to pay: $46.93 per square meter (i.e., $4.36 per square foot). This suggests that, without additional incentives or cost-sharing financial assistance programs, growers' current WTP may not be sufficient to cover the full cost of high-end high tunnel construction. In contrast, lower-cost options such as caterpillar tunnels, estimated at under $38.00 per square meter (i.e., $3.53 per square foot) in Florida (Nian et al. 2023), fall within growers' WTP. It indicates that caterpillar tunnels may present a more attainable entry point for growers' adoption of tunnels in their production systems. Only 23% of the respondents know where they can get support when encountering issues related to high tunnel crop production. Moreover, 53% of the respondents know about the USDA-NRCS financial assistance program to assist growers in high tunnel purchase and installation (Table 1).

*Growers' perceptions of high tunnels.* Table 2 shows growers' perceptions of high tunnels. In general, growers tend to have positive perceptions of high tunnels. Regarding the impact of high tunnels on crop production outcomes, growers tend to perceive that high tunnels could improve crop yield and quality, extend the growing season, and reduce the risk of crop loss caused by severe weather conditions. In terms of crop management in high tunnels, more than 50% of growers perceive that high tunnels can improve soil

Table 2. Specialty growers' perceptions of high tunnels in Florida.

| | High tunnel users | | High tunnel nonusers | | $\chi^2$ |
|---|---|---|---|---|---|
| Statement | *N* | Percent (%) | *N* | Percent (%) | statistics |
| High tunnels would increase crop yields | 32 | 100 | 30 | 100 | $1.128^{NS}$ |
| Strongly disagree | 1 | 3 | 0 | 0 | |
| Disagree | 0 | 0 | 0 | 0 | |
| Neutral | 4 | 12 | 5 | 17 | |
| Agree | 16 | 50 | 15 | 50 | |
| Strongly agree | 11 | 34 | 10 | 33 | |
| High tunnels would improve crop quality | 32 | 100 | 30 | 100 | $2.475^{NS}$ |
| Strongly disagree | 1 | 3 | 1 | 3 | |
| Disagree | 0 | 0 | 0 | 0 | |
| Neutral | 5 | 16 | 4 | 13 | |
| Agree | 15 | 47 | 9 | 30 | |
| Strongly agree | 11 | 34 | 16 | 53 | |
| High tunnels would extend growing seasons | 32 | 100 | 30 | 100 | $1.955^{NS}$ |
| Strongly disagree | 2 | 6 | 1 | 3 | |
| Disagree | 1 | 3 | 2 | 7 | |
| Neutral | 2 | 6 | 1 | 3 | |
| Agree | 13 | 41 | 9 | 30 | |
| Strongly agree | 14 | 44 | 17 | 57 | |
| High tunnels would reduce the risk of crop loss caused by severe weather conditions | 32 | 100 | 30 | 100 | $2.676^{NS}$ |
| Strongly disagree | 1 | 3 | 1 | 3 | |
| Disagree | 0 | 0 | 0 | 0 | |
| Neutral | 6 | 19 | 2 | 7 | |
| Agree | 13 | 41 | 11 | 37 | |
| Strongly agree | 12 | 38 | 16 | 53 | |
| High tunnels would improve soil quality | 32 | 100 | 30 | 100 | $2.825^{NS}$ |
| Strongly disagree | 1 | 3 | 0 | 0 | |
| Disagree | 2 | 6 | 4 | 13 | |
| Neutral | 14 | 44 | 14 | 47 | |
| Agree | 9 | 28 | 5 | 17 | |
| Strongly agree | 6 | 19 | 7 | 23 | |
| High tunnels would reduce nutrient losses and improve the nutrient use efficiency | 32 | 100 | 30 | 100 | $1.99^{NS}$ |
| Strongly disagree | 1 | 3 | 0 | 0 | |
| Disagree | 1 | 3 | 2 | 7 | |
| Neutral | 5 | 16 | 7 | 23 | |
| Agree | 15 | 47 | 12 | 40 | |
| Strongly agree | 10 | 31 | 9 | 30 | |
| High tunnels would improve air quality through reduced transportation inputs | 32 | 100 | 30 | 100 | $5.434^{NS}$ |
| Strongly disagree | 1 | 3 | 1 | 3 | |
| Disagree | 1 | 3 | 4 | 13 | |
| Neutral | 14 | 44 | 11 | 37 | |
| Agree | 12 | 38 | 6 | 20 | |
| Strongly agree | 4 | 12 | 8 | 27 | |
| High tunnels would reduce energy use by providing consumers with a local source of fresh produce | 32 | 100 | 30 | 100 | $4.027^{NS}$ |
| Strongly disagree | 2 | 6 | 0 | 0 | |
| Disagree | 1 | 3 | 2 | 7 | |
| Neutral | 5 | 16 | 5 | 17 | |
| Agree | 10 | 31 | 14 | 47 | |
| Strongly agree | 14 | 44 | 9 | 30 | |
| Over the long run, high tunnels would be a major contributor to farms' current financial profitability | 32 | 100 | 30 | 100 | $1.391^{NS}$ |
| Strongly disagree | 1 | 3 | 0 | 0 | |
| Disagree | 1 | 3 | 2 | 7 | |
| Neutral | 7 | 22 | 6 | 20 | |
| Agree | 12 | 38 | 11 | 37 | |
| Strongly agree | 11 | 34 | 11 | 37 | |
| High tunnels will be important for your farm to remain competitive in the coming decade | 32 | 100 | 30 | 100 | $2.486^{NS}$ |
| Strongly disagree | 3 | 9 | 1 | 3 | |
| Disagree | 1 | 3 | 0 | 0 | |
| Neutral | 8 | 25 | 6 | 20 | |
| Agree | 8 | 25 | 10 | 33 | |
| Strongly agree | 12 | 38 | 13 | 43 | |

$^{NS}$ in the column of $\chi^2$ statistics indicates that the $\chi^2$ test is not statistically significant at $\alpha = 0.1$.



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quality, enhance nutrient use efficiency, increase air quality, and reduce energy use by allowing growers to supply crops to local consumers reducing. The result differs from previous findings, which show that long-term soil fertility can be a significant challenge for high tunnel production (Fitzgerald and Hutton 2012; Knewtson et al. 2012; Rudisill et al. 2015). Moreover, over half of grower respondents perceive that high tunnels can be essential to keep farm business profitable and help farms remain competitive in the coming years. These results are consistent with findings of studies with growers from the Midwest United States, where growers often view high tunnels as a strategic tool to extend the production season, improve crop yield and quality, and strengthen farm businesses (Bruce et al. 2019, 2021).

Last, we conducted a $\chi^2$ test to examine whether growers who used high tunnels and those who did not had similar perceptions. We found no statistical difference in growers' perceptions between high tunnel users and nonusers (Table 2). This suggests that the potential benefits of high tunnels are well diffused among Florida specialty crop growers, so the nonadoption might not be primarily due to a lack of positive perceptions of high tunnels.

*Growers' crop production practices in high tunnels.* Figure 1 shows the style of high tunnels that current high tunnel users are using. There are four common styles of high tunnels: (1) Quonset style characterized by a round steel arch; (2) Gothic style characterized by a peaked roof (used to help shed snow) that requires additional bracing to withstand winds; (3) multibay style with side-by-side high tunnels connected at the roof by gutters; and (4) caterpillar style that does not include baseboards or built-in end and side walls but features cone-shaped ends with extended plastic films that hug the ground at both ends (Nian et al. 2023). Our results indicate that the Quonset style is most commonly used by growers. The second most widely used type is the Gothic style, followed by the caterpillar and multibay styles. This result is slightly different from findings from Kentucky, where the Gothic style is more popular than the Quonset style (Ernst et al. 2020). The primary benefit of Gothic-style high tunnels is that the peaked roof can help shed snow (Nian et al. 2023). Given that Florida rarely experiences snowy weather, it is reasonable that Florida specialty crop growers prefer the Quonset style over the Gothic style. The multibay style high tunnels are the least prevalent, possibly because of their high cost.

Figure 2 shows the number of years since current high tunnel users have adopted them. The average time since the adoption of high tunnels is 6.8 years. Around 58% of current users have been using high tunnels for between 3 and 6 years. The results also differ from those in Kentucky, where most growers have been using high tunnels for 10 years or more (Ernst et al. 2020). This suggests that high tunnel adoption among Florida growers has generally been slower compared with leading adoption states like Kentucky. In Florida, the maximum time since adoption is 17 years, while the minimum time is 1 year. This indicates that growers have varying levels of experience in high-tunnel specialty crop production.

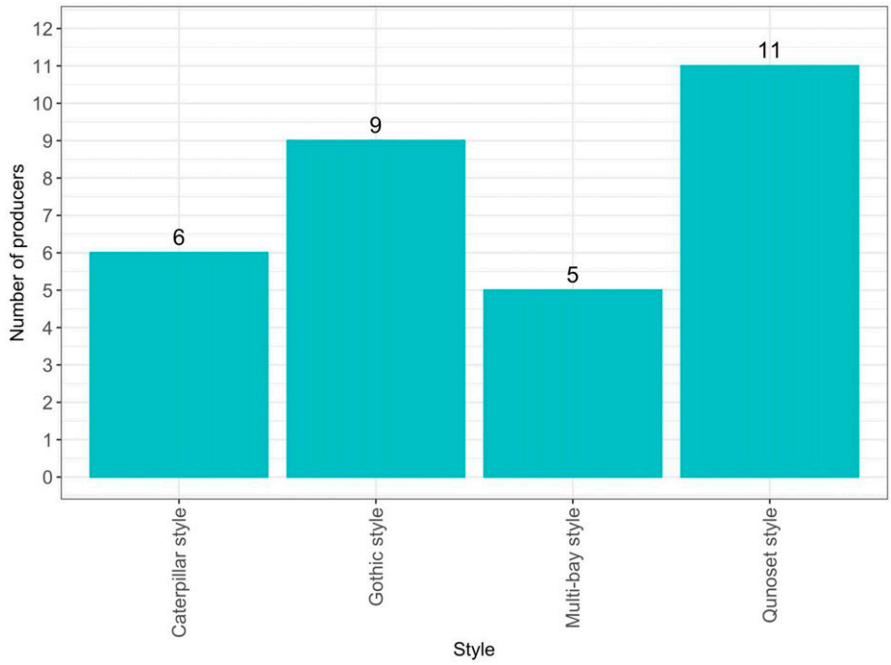


Fig. 1. Number of current high tunnel users using different styles of high tunnels in Florida.

Most current high tunnel users always grow multiple crops in the same season in high tunnels. Only a tiny proportion of current high tunnel users grow one crop in a season in high tunnels (Fig. 3). In addition, 80% of current high tunnel users grow crops using in-ground soil cultivation systems in high tunnels. A small proportion of current high tunnel users use diverse cultivation systems, such as media-based hydroponic systems, solution-based hydroponic systems, and container systems, to grow crops in high tunnels (Fig. 4). Meanwhile, most current high tunnel users employ organic production practices in their high tunnel operations (Fig. 5).

*Factors correlated to growers' adoption decisions.* Table 3 shows the estimated average marginal effects of factors influencing growers' use of high tunnels from the probit

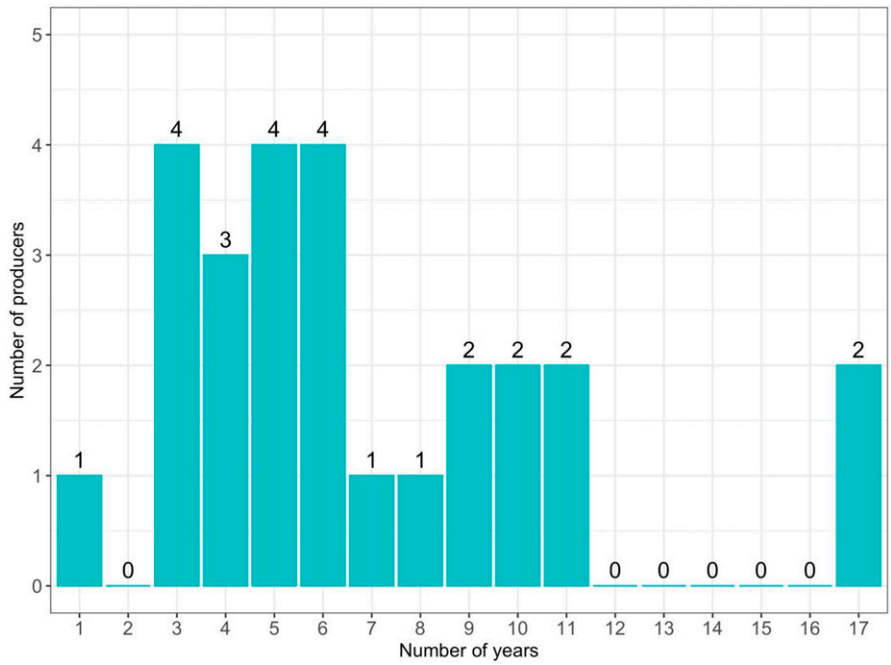


Fig. 2. Variation in years since the adoption of high tunnels by current high tunnel users in Florida.



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model. To assess the robustness of our results, we included different sets of explanatory variables across five model specifications. Column 1 includes only information and policy awareness variables; column 2 includes only variables related to growers' perceptions of high tunnels; column 3 includes only farm characteristic variables; column 4 includes only sociodemographic characteristics; and column 5 includes all variables.

Among these, the model in column 5 is preferred, as it shows the best model fitness indicated by the highest log-likelihood value and pseudo $R^2$. The likelihood ratio test of the most preferred model in column 5 rejects the null hypothesis that all regression coefficients jointly do not affect growers' decisions. In the preferred model, the coefficient of awareness of the source of high tunnel information is insignificant, suggesting that whether growers know places to gain knowledge of high tunnel production is not likely correlated with their decision to adopt high tunnels. The coefficient of awareness of the USDA-NRCS financial assistance program is positive and significant at the 5% significance level, suggesting that growers who know the USDA-NRCS high tunnel financial assistance program are more likely to use high tunnels. The magnitude of the coefficient is the second largest among all coefficients, suggesting that increasing growers' awareness of the USDA-NRCS high tunnel financial assistance program can be one of the most crucial factors affecting growers' high tunnel adoption decisions. Among growers' perceptions of high tunnels, neither coefficient is statistically significant, suggesting that growers' perceptions of high tunnels are not an important factor correlated with growers' high tunnel adoption decisions.

Among farm characteristics, the coefficient of corporate ownership is positive and significant at the 1% significance level, and the magnitude of the coefficient is the largest, suggesting that growers whose land is owned by themselves as a corporation are more likely to adopt high tunnels. The coefficient of the natural log of farm size in acres is negative and significant at the 10% significance level, suggesting that the smaller farms are more likely to adopt high tunnels than the larger farms in Florida. This echoes the findings from Conner and Demchak (2018), who conducted interviews with growers to understand their attitudes toward high tunnel adoption. The Midwest US growers noted that high tunnels are "difficult to scale" because they are "not easily automated." As a result, larger operations often face labor constraints that limit the feasibility of adopting this technology.

Among demographic characteristics, the coefficients for females, Hispanics, and education are not statistically significant, indicating that gender, Hispanic ethnicity, and education level are not correlated with growers' adoption of high tunnels. In contrast, the coefficient for white growers is positive and significant at the 10% significance level, indicating that white growers are more likely to adopt high tunnels.

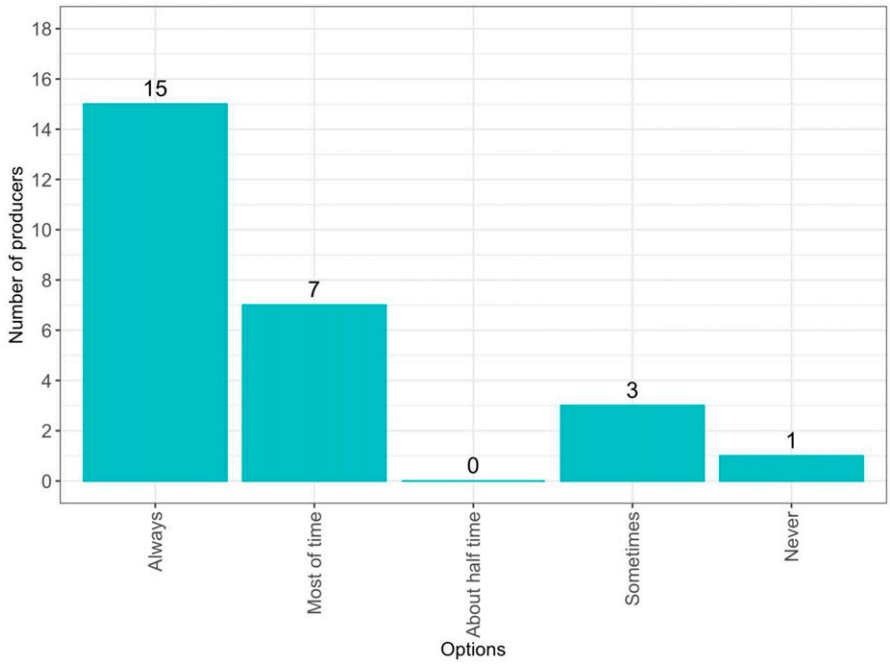


Fig. 3. Number of current high tunnel users growing multiple crops during the same season in high tunnels in Florida.

Taken together, previous studies have implied that financial constraints, such as high upfront installation costs, can be the primary barrier to high tunnel use in the United States (Bruce et al. 2019; Rowley et al. 2010). Our results imply that informing growers, particularly small and midsized growers, about the available financial assistance programs for high tunnels can be crucial for increasing high tunnel use among specialty crop growers. Those financial assistance programs can help reduce growers' financial burden associated with high tunnel construction.

Table 4 reports the linear regression model results, revealing whether and to what extent different factors may be correlated with growers' WTP for high tunnels. The model in column 1 includes only high tunnel use experience as explanatory variables; the model in column 2 includes only information and policy awareness variable; the model in column 3 includes only variables related to growers' perceptions of high tunnels; the model in column 4 includes only farm characteristic variables; the model in column 5 includes only sociodemographic characteristics; and column 6 includes all variables. By

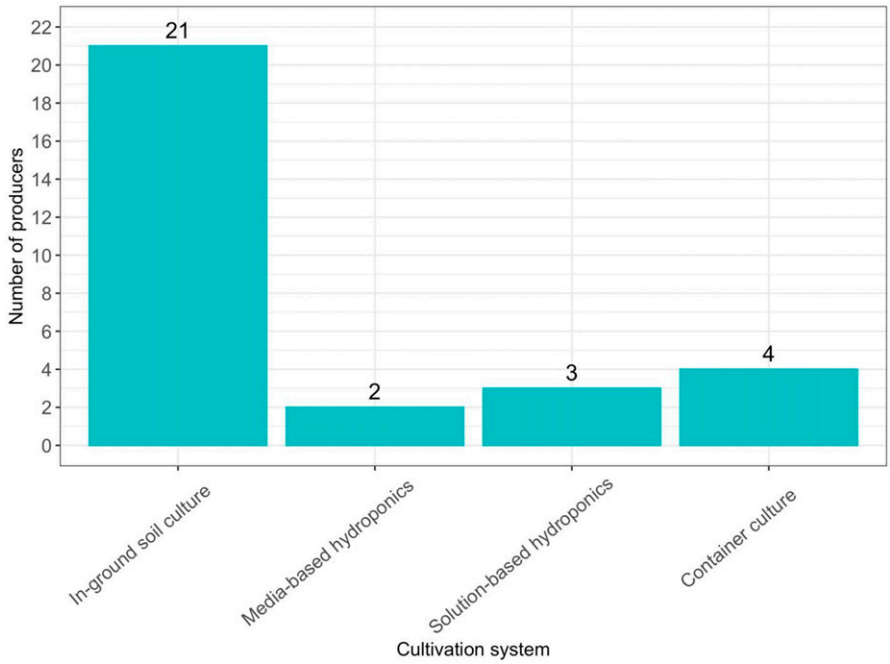


Fig. 4. Number of current high tunnel users using different cultivation systems in high tunnels in Florida.



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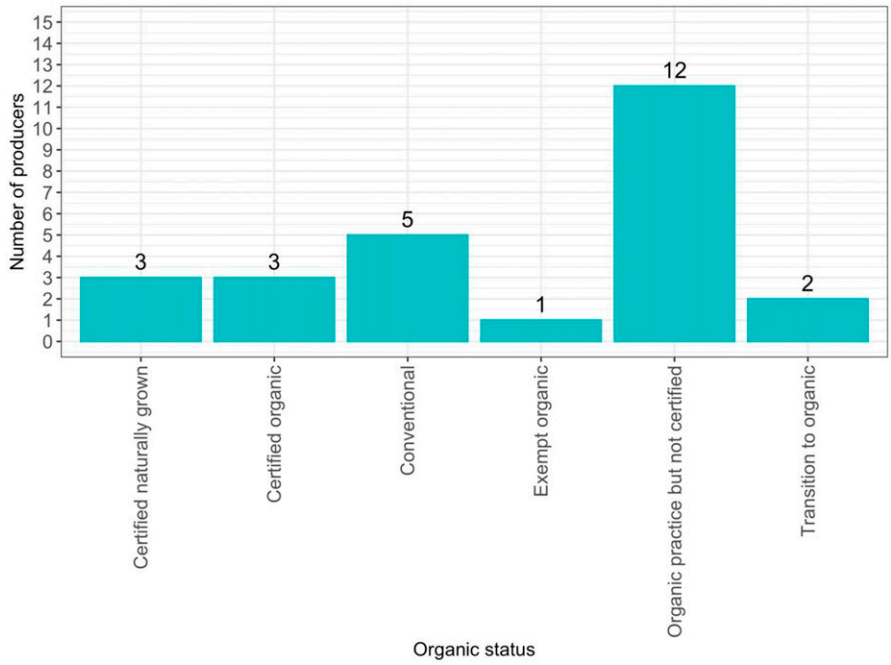


Fig. 5. Number of producers using organic or conventional production systems among current high tunnel users in Florida.

using the stepwise selection method to add different variables to the model, we can assess the robustness of the results across different model specifications. Only the variable of the natural log of farm sales is consistently statistically significant at the 10% significance level in different models. It suggests that growers with higher farm sales values tend to have a higher WTP for building new high tunnels. Growers' WTP for high tunnels is not likely to consistently correlate with other farm characteristics, such as farm size, land ownership type, years of farming experience, farm market channels, perceptions of high tunnels, sociodemographics, and knowledge of policy and information support for high tunnels in different model specifications.

## Conclusions

High tunnels are a relatively low-cost protected agriculture systems that enable specialty crop growers, especially small and midsized growers, to mitigate production risks. This study examines growers' perceptions, identifies factors correlated with high tunnel adoption, and documents their experiences with this technology in Florida.

Table 3. Estimated average marginal effects of explanatory variables on growers' likelihood to use high tunnels in Florida using the probit regression model.

| Variable | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Information and policy awareness | | | | | |
| Aware of the source of high tunnel information | 0.004 | ND | ND | ND | 0.084 |
| | (0.161) | ND | ND | ND | (0.164) |
| Aware of the NRCS financial assistance program | 0.260* | ND | ND | ND | 0.302** |
| | (0.135) | ND | ND | ND | (0.136) |
| Perceptions | | | | | |
| Perception of production outcomes | ND | 0.076 | ND | ND | 0.038 |
| | ND | (0.076) | ND | ND | (0.077) |
| Perception of crop management | ND | −0.035 | ND | ND | 0.011 |
| | ND | (0.071) | ND | ND | (0.069) |
| Farm characteristics | | | | | |
| Land ownership – corporate | ND | ND | 0.531*** | ND | 0.505*** |
| | ND | ND | (0.178) | ND | (0.187) |
| Natural log of farm size | ND | ND | −0.090** | ND | −0.074* |
| | ND | ND | (0.037) | ND | (0.039) |
| Natural log of farm sales value | ND | ND | 0.041* | ND | 0.038 |
| | ND | ND | (0.023) | ND | (0.025) |
| Years of farming experience | ND | ND | 0.002 | ND | 0.007 |
| | ND | ND | (0.006) | ND | (0.006) |
| Direct to consumers | ND | ND | −0.031 | ND | −0.002 |
| | ND | ND | (0.161) | ND | (0.180) |
| Sociodemographic characteristics | | | | | |
| Female | ND | ND | ND | −0.028 | −0.103 |
| | ND | ND | ND | (0.139) | (0.132) |
| Hispanic | ND | ND | ND | 0.064 | 0.135 |
| | ND | ND | ND | (0.244) | (0.241) |
| White | ND | ND | ND | 0.158 | 0.253* |
| | ND | ND | ND | (0.138) | (0.144) |
| College | ND | ND | ND | 0.105 | 0.205 |
| | ND | ND | ND | (0.193) | (0.184) |
| Graduate degree | ND | ND | ND | 0.203 | 0.248 |
| | ND | ND | ND | (0.221) | (0.218) |
| Log-likelihood | −42.782 | −44.445 | −38.110 | −43.171 | −31.184 |
| $\chi^2$ statistics | 4.369 | 1.044 | 13.716** | 5.593 | 27.567** |
| Pseudo $R^2$ | 0.068 | 0.017 | 0.198 | 0.056 | 0.389 |
| Observations | 62 | 62 | 62 | 62 | 62 |

The estimated coefficients are reported as numbers in the table, with the standard errors shown in parentheses. Column 1 includes only information and policy awareness variables; column 2 includes only variables related to growers' perceptions of high tunnels; column 3 includes only farm characteristic variables; column 4 includes only sociodemographic characteristics; and column 5 includes all variables. ***, **, and * indicate statistical significance at $\alpha = 0.01$, 0.05, and 0.1, respectively. ND = no data; NRCS = Natural Resources Conservation Service.



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Table 4. Estimated effects of explanatory variables on growers' willingness to pay for high tunnels in Florida using the linear regression model.

| Variable | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| High tunnels use experience | | | | | | |
| Use or have used high tunnels | 1.452* | ND | ND | ND | ND | 0.906 |
| | (0.736) | ND | ND | ND | ND | (0.881) |
| Information and policy awareness | | | | | | |
| Aware of the source of high tunnel information | ND | 0.605 | ND | ND | ND | 0.304 |
| | ND | (0.960) | ND | ND | ND | (0.993) |
| Aware of the NRCS financial assistance program | ND | 0.846 | ND | ND | ND | 0.587 |
| | ND | (0.805) | ND | ND | ND | (0.865) |
| Perceptions | | | | | | |
| Perception of production outcomes | ND | ND | 0.546 | ND | ND | 0.247 |
| | ND | ND | (0.447) | ND | ND | (0.466) |
| Perception of crop management | ND | ND | −0.172 | ND | ND | 0.036 |
| | ND | ND | (0.416) | ND | ND | (0.419) |
| Farm characteristics | | | | | | |
| Land ownership – corporate | ND | ND | ND | 1.751* | ND | 0.679 |
| | ND | ND | ND | (1.028) | ND | (1.212) |
| Natural log of farm size | ND | ND | ND | −0.024 | ND | 0.152 |
| | ND | ND | ND | (0.214) | ND | (0.242) |
| Natural log of farm sales value | ND | ND | ND | 0.264* | ND | 0.269* |
| | ND | ND | ND | (0.130) | ND | (0.152) |
| Years of farming experience | ND | ND | ND | 0.059* | ND | 0.044 |
| | ND | ND | ND | (0.032) | ND | (0.036) |
| Direct to consumers | ND | ND | ND | 1.463 | ND | 1.078 |
| | ND | ND | ND | (0.927) | ND | (1.085) |
| Sociodemographic characteristics | | | | | | |
| Female | ND | ND | ND | ND | 0.749 | 0.784 |
| | ND | ND | ND | ND | (1.135) | (0.799) |
| Hispanic | ND | ND | ND | ND | −0.669 | 0.451 |
| | ND | ND | ND | ND | (1.405) | (1.457) |
| White | ND | ND | ND | ND | −0.833 | −0.531 |
| | ND | ND | ND | ND | (0.796) | (0.895) |
| College | ND | ND | ND | ND | −1.076 | −0.925 |
| | ND | ND | ND | ND | (1.113) | (1.126) |
| Graduate degree | ND | ND | ND | ND | 0.545 | 0.699 |
| | ND | ND | ND | ND | (1.272) | (1.332) |
| Constant | 3.907*** | 4.022*** | 2.923 | 2.631*** | 5.224*** | 0.862 |
| | (0.512) | 0.553 | (1.934) | (0.723) | (1.135) | (2.740) |
| F statistics | 3.889* | 1.124 | 0.748 | 3.360** | 1.189 | 1.575 |
| $R^2$ | 0.067 | 0.037 | 0.025 | 0.231 | 0.096 | 0.339 |
| Adjusted $R^2$ | 0.045 | 0.004 | −0.008 | 0.162 | 0.015 | 0.124 |
| Observations | 62 | 62 | 62 | 62 | 62 | 62 |

The estimated average marginal effect coefficients are reported as numbers in the table, with the standard errors shown in parentheses. The model in column 1includes only high tunnel use experience as explanatory variables; the model in column 2 includes only information and policy awareness variable; the model in column 3 includes only variables related to growers' perceptions of high tunnels; the model in column 4 includes only farm characteristic variables; the model in column 5 includes only sociodemographic characteristics; and column 6 includes all variables. ***, **, and * indicate statistical significance at $\alpha = 0.01$, 0.05, and 0.1, respectively. NRCS = Natural Resources Conservation Service.

Our results demonstrate that both high tunnel users and nonusers have positive perceptions of high tunnels in all aspects, including their economic implications, crop production practice implications, and crop production outcomes. Specialty crop high tunnel users tend to have various years of high tunnel use experience. The most popular high tunnels are Quonset style, and growers tend to produce multiple crops and use in-ground soil cultivation systems to produce specialty crops in high tunnels. Although most growers' farm and sociodemographic characteristics have little relationship with their WTP for building new high tunnels, their actual use of high tunnels is correlated with a few farm characteristics, such as farm size and land ownership, and demographic characteristics such as race. In addition, growers' knowledge of the USDA-NRCS high tunnel financial assistance program can greatly incentivize them to adopt high tunnels.

Several opportunities exist for future research. First, the survey we analyzed only includes 62 valid and complete responses. Future studies may explore more innovative methods to collect a larger sample size to study growers' perspectives on using high tunnels. Second, the study only focuses on Florida specialty crop growers. Future studies may include more growers who produce different crops in other regions to study whether and to what extent growers' perspectives may differ due to geological factors. Finally, in this study, we identified correlations between farmers' use of high tunnels and certain influencing factors, but we did not conclude on the causal relationship between these factors and farmers' use of high tunnels. Future research should consider employing better identification strategies to establish causal relationships. Such insights would be critical for developing targeted promotion strategies to encourage greater adoption of high tunnels among growers. Future studies may also consider collecting farm-level economic data to quantify the financial implications of using high tunnels for specialty crop production.

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