RESEARCH ARTICLE

Walnut growers want rootstocks that can resist diseases

California walnut growers are willing to pay more for disease-resistant rootstocks.

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Online: https://doi.org/10.3733/001c.94526

Abstract

English walnuts are the walnut species of choice for nut production. In the United States, edible English walnuts are almost exclusively produced in California, using soil and water resources on more than 370,000 acres. Scion cultivars of English walnuts are grafted onto rootstocks. Traditional rootstocks are seedling populations of so-called Paradox hybrids generated from crosses of black walnut with English walnut. These rootstocks are susceptible to soil-borne diseases, including crown gall, Phytophthora root and crown rot, and plant-parasitic nematodes. Strategies to respond to these diseases include the use of newly developed clonal walnut rootstocks with genetic resistance. In a survey conducted during 2020 through 2021, walnut growers revealed their willingness to pay higher prices for clonal walnut rootstocks with some disease resistance. The survey showed that they were most concerned with crown gall and nematodes, and were willing to pay significant price premiums for rootstocks that are resistant to these pathogens.

Tree nut production, including walnuts, is among the most important agricultural industries in California. California is the leading producer of edible English walnuts in the United States, accounting for nearly 100% of domestic production and 38% of the world export supply (Workman 2022). In 2019, California walnut exports were valued at $958 million (CDFA 2020), accounting for nearly 63% of the returns to the California walnut crop (California Walnuts 2022).

The production efficiency of the walnut industry is critical to farmers and the California economy alike (Liang et al. 2020; Woolwine et al. 2020). The purpose of this research was to assess walnut growers' expectations of improved rootstocks and their willingness to pay for recently developed walnut rootstocks. Clonally propagated rootstocks were selected for having some disease resistance, some drought tolerance, and higher levels of uniformity compared to traditionally used rootstocks. These beneficial characteristics improve walnut production efficiencies and sustainability because they require less pesticide and water, in addition

An English walnut orchard in Red Bluff, California. In a recent study, researchers assessed walnut growers' willingness to pay for new rootstocks with disease resistance. *Photo:* Demujin, iStock.

to decreasing costs per unit to growers through labor efficiencies. The reduced pesticide and water inputs improve overall environmental quality. This study can help nurseries better anticipate the rootstock attributes requested by growers, and can provide estimates of ranges of price premiums that growers are willing to pay for these attributes.

At the beginning of the walnut industry in California in the mid- to late 1800s, edible walnuts were produced by grafting English scions onto black walnut rootstocks. At the turn of the twentieth century and into the 1900s, more vigorous so-called Paradox rootstocks were introduced. Luther Burbank found that hybrid seedlings of a cross of Northern California black (*Juglans hindsii*) with English walnut (*J. regia*) conferred superior vigor, and he called them Paradox because of this surprising result, prior to a general understanding of hybrid vigor (Preece and McGranahan 2015).

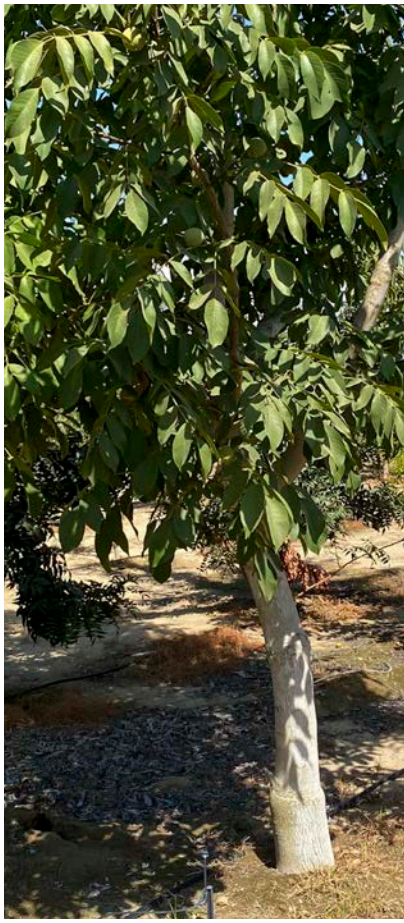
Paradox rootstocks have since become the mainstay for walnut production in California. Despite their vigor, use of Paradox seedlings can result in non-uniform orchards with pathogen-susceptible roots. A study comparing average performance of Paradox seedling populations from various mother trees allowed elimination of several poorly performing seed sources (Beede et al. 2007) but did not identify sources of pathogen resistance for which breeders could select. The infertility of interspecific crosses in most cases, and the extended juvenile phase of walnuts, have encumbered breeding for rootstock disease resistance, which has been commonly done in other crops, including other tree crops. However, by using advanced laboratory techniques, individual trees of interest can be micro-propagated to generate new plants that can be evaluated as novel rootstocks possessing unique fixed genetic traits. In this way, three clonal (vegetatively propagated) walnut rootstocks were developed and made commercially available: Phytophthora-resistant 'RX1' rootstock (McGranahan et al. 2010a), the root lesion nematode-tolerant rootstock 'VX211' (McGranahan et al. 2010b), and, before that, the vigorous 'Vlach'.

Clonal rootstocks in an orchard frequently have less crown gall infection than seedlings. In part, this may be the case because plants produced in the laboratory are not exposed to early infection by the soil-borne pathogen *Agrobacterium tumefaciens*. In contrast, in traditional seedling production, the nuts giving rise to the rootstock may already be infected if harvested from the ground underneath the mother tree (Yakabe et al. 2014). Using genetically resistant clonal rootstocks can help manage key soil-borne diseases, and such rootstocks have been widely adopted since first introduced. In addition, clonal techniques enable the production of new unique interspecific hybrids. Interspecific crosses can be made, and superior breeding lines with combinations of resistance and tolerance to multiple pathogens can be selected. These techniques allow mass production of such genotypes, which then can be used as novel rootstocks. New rootstocks are highly desired by growers, but rootstocks with resistance against multiple pathogens are currently lacking in the walnut industry. Recently, researchers have generated diverse sets of directed crosses of different walnut species. Testing such hybrids is underway and promising elite rootstocks with multiple disease-averting properties have been selected. This article, which asks about grower awareness of soil-borne diseases and preferences for rootstock, focuses on the currently commercially available clonal rootstocks RX1, Vlach and VX211.

A survey of walnut growers was developed to get firsthand data to analyze growers' production practices and their decision-making in adopting new technologies (e.g., Mack et al. 2017; Tautges et al. 2016). The survey was designed to be multi-regional. This aligns with California walnut production areas, and is consistent with recent studies that emphasize the regional variation in agricultural economies (e.g., Liang 2017; Liang and Goetz 2016; Liang and Goetz 2018; Wilson et al. 2019). Regarding the tree nut industry in California, many scholars have pointed out that cost-efficiency, information dissemination, and growers' cooperation are essential for on-farm adoption of new technologies (Grant et al. 2003; Haroldsen et al. 2012; Leslie and McGranahan 2014). In the present survey, we tested the hypothesis that growers are aware of their production challenges. We further surveyed growers to determine the extent to which this knowledge resulted in actual decisions in rootstock choice and production strategies.

Enhanced walnut rootstocks

A consortium of 16 research groups is tackling the tedious process of improving walnut rootstocks. Expertise ranges from classical and molecular breeding, plant physiology, horticulture, plant pathology, molecular biology, and agricultural engineering to economic and outreach activities. This consortium has participants from three University of California campuses, the USDA Agricultural Research Service, California State University at Fresno, and University of California Agriculture and Natural Resources. Supported by federal, state and California Walnut Board grants, the program is designed to investigate the challenges using a comprehensive approach. The process begins with the generation of genetic diversity that can be exploited for favorable traits. Based on prior information about superior mother trees, crosses are made with these trees. Nuts of these crosses are used to propagate clonal saplings of distinct genotypes, via embryo rescue and tissue culture techniques (Leslie and McGranahan 2014). These plants then enter the pathogen testing pipelines for crown gall, Phytophthora root and crown rots, and plant-parasitic nematodes (Ramasamy et al. 2021; Westphal et al. 2021). Selected genotypes are also examined for susceptibility to the Cherry leaf roll virus (M. Sudasharna, USDA-ARS, Davis, unpublished data). While crown gall and Phytophthora are tested in



Above, Chandler rootstock; *below*, RX1 rootstock. *Photos*: Andreas Westphal.

greenhouse experiments (which last six months or less), the nematode testing occurs under field conditions over two to three years. Nematode experiments also produce some preliminary data on vigor for various rootstock siblings, which can provide additional guidance in the selection process. In parallel to these selection studies, all genotypes are maintained in tissue culture.

Selected from these large screening efforts, genotypes are submitted to specialized tests for additional parameters. For example, the water relations (surplus or deficiency) in pathogen response-defined clones are fruitful in tying together different traits of the elites (Knipfer et al. 2020). Plantings of genotypes with distinct pathogen responses serve as testing ground for studies in the field using remote sensing. Two engineering groups have standardized independent strategies for detecting nematode-induced changes in walnut trees (Niu et al. 2021; Omidi et al. 2022). In parallel, geneticists are developing genetic maps to identify markers for the traits of interest to develop information on the genetic background; this may allow for genetic marker-assisted selection of novel genotypes that combine multiple types of resistance (Ramasamy et al. 2021).

The growers were highly interested in adopting advanced technologies such as new rootstocks to deal with problems, and they were willing to pay price premiums.

To further the development of rootstocks for commercial use, frontrunner candidates of the elite rootstocks are being tested in different agro-ecological environments to determine their field performance under commercial conditions. The same scion is used in order to compare rootstock performance under uniform conditions. This final and most time-consuming step determines the performance of the new rootstocks as grafted trees when they are challenged for growth and yield performance.

All these studies are being conducted with feedback and discussion with stakeholder leaders. This survey and follow-up telephone interviews were conducted to further ensure that the overall rootstock development program is relevant to growers.

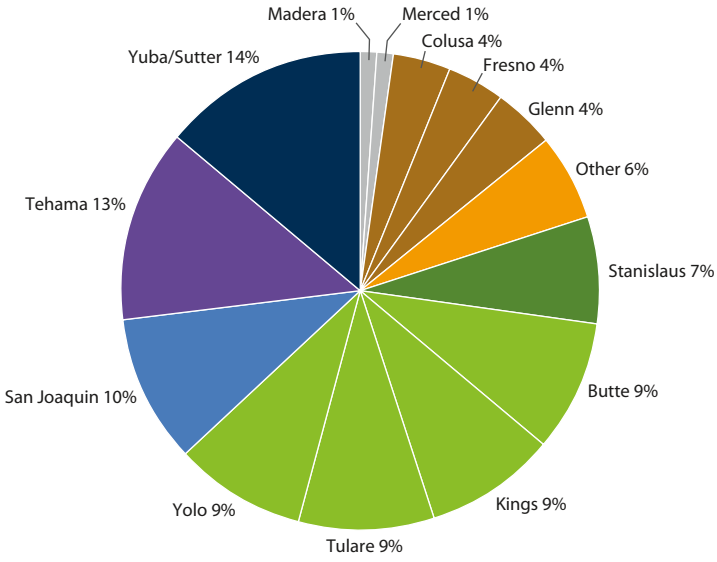


FIG. 1. County distribution of survey respondents.

Interviewing the growers

Despite the many advantages of these new types of rootstocks, potential benefits can only be harnessed if growers accept their value and utility. In this research, the objective was to collect firsthand information from California walnut growers and determine what factors affect their decision-making. The survey considering growers' farming experience asked the following: Which pests, disease and drought pressures concern walnut growers the most? What are growers' selection preferences for walnut rootstock in regard to disease resistance? What premiums are walnut growers willing to pay above conventionally priced rootstocks for the novel ones with pathogen resistance or drought tolerance?

The survey consisted of 29 questions about walnut production operations, as well as some demographic data. Members of the Walnut Research Advisory Panel reviewed the survey to ensure that growers would be receptive. The finalized version was approved by the Human Subjects Institutional Review Board (IRB) of California State University, Fresno, in fall 2019.

The approved walnut grower survey was administered in a Qualtrics link and paper-and-pencil version at grower meetings and online from January 2020 through summer 2021. The version was distributed at grower events through March 2020. Data from the paper-and-pencil survey were tabulated and used together with online responses in the analysis.

Upon completion of the online survey, additional walnut growers were interviewed by phone to validate and refine the results of the online and paper survey. The phone survey consisted of 12 questions focused on current production practices and rootstock selection.

Seventy-four growers responded to the survey, equivalent to 2% of about 4,000 California walnut growers (California Walnuts 2022). This number of respondents passes the typical tests for survey statistics such as the "large sample size of 30" and "10 times dependent variables of regression." Given the total walnut grower population, our 2% sampling size yields better than 90% confidence (Tourangeau 2019). The top five walnut-producing counties in California are San Joaquin, Stanislaus, Tulare, Butte and Sutter, which account for 50% of all walnut acreage in California. As illustrated in figure 1, 49% of our survey respondents were from those five counties. Thus, the distribution of survey respondents aligns proportionately with California walnut production by county (Geisseler and Horwath 2016).

Disease issues and their distributions in the walnut-growing areas are generally similar throughout California, with the exception of blackline disease; this observation is based on our meetings with growers and discussions within the farm advisor continuum and the Production Research Advisory Committee of the California Walnut Board (more details can be seen in the online technical appendix of this paper). Therefore, our surveying method and the sample size generated representative statistical results for California walnut growers.

Pathogens affecting walnuts

One of the key questions in the survey was what problems growers are experiencing in their walnut production operations. As shown in figure 2, almost 80% of respondents reported having issues with crown gall; this was the most frequent response, followed by root rot (Phytophthora) (54.1%) and root lesion nematode (45.9%), which generally includes "replanting problems." The frequency with which problems were mentioned was reflected by the average ranking that growers assigned to each production issue, as shown in figure 3. Crown gall was ranked with the highest importance, followed by Phytophthora root and crown rot and nematodes.

In response to the question about growers' interest in a walnut rootstock that is resistant to specific soil-related disease problems (table 1), a large percentage of growers showed strong interest in rootstocks that featured resistance to crown gall, Phytophthora root and crown rot, and root lesion nematode/replant problems (in order of decreasing interest).

The growers' willingness to pay (WTP) for rootstocks resistant to certain issues varied among different pathogens, as shown in table 2. Respondents answered more conservatively about the premium they were willing to pay relative to their answers about the problems they faced. There was uncertainty about what premium they would be willing to pay for these advanced walnut attributes, but 50% or more of the

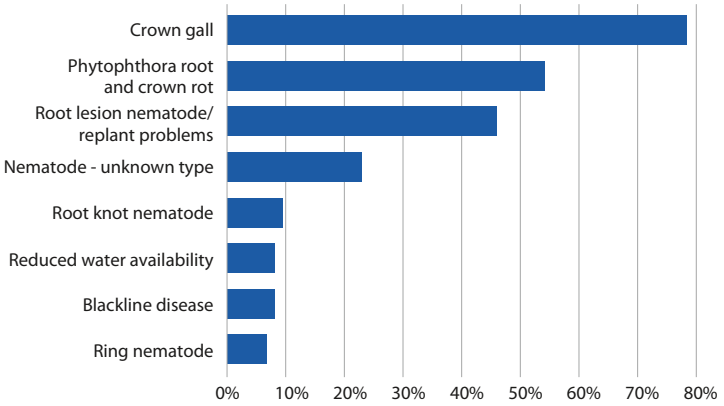


FIG. 2. Walnut grower issues indicated by percent of respondents.

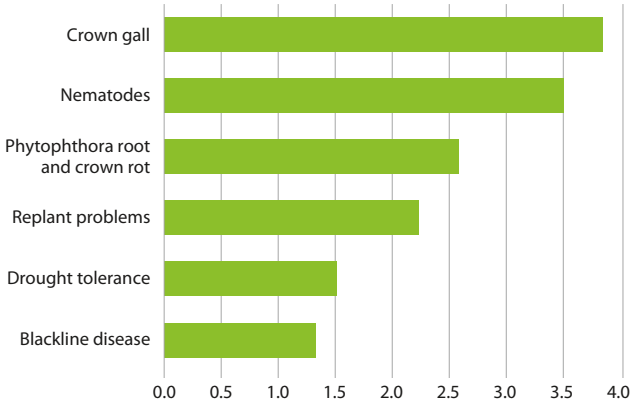


FIG. 3. Average importance of production issues (most important = 5; least = 1).

TABLE 1. Growers' interest in access to a walnut rootstock resistant to soil-related issues (percent of growers)

	Root lesion nematode	Root knot nematode	Ring nematode	Crown gall	Root rot*	Blackline disease	Drought (tolerant)
Very interested	56%	41%	42%	86%	68%	26%	36%
Somewhat interested	25%	35%	27%	4%	19%	38%	41%
Not interested	3%	3%	5%	0%	0%	12%	7%
Uncertain	15%	22%	26%	9%	14%	24%	16%

* i.e., Phytophthora root and crown rot.

TABLE 2. Answers to "How much more would you be willing to pay for rootstock that is resistant to the following issues?" (percent of growers)

	Root lesion nematode	Root knot nematode	Ring nematode	Crown gall	Root rot*	Blackline disease	Drought (tolerant)
30% more	20%	10%	12%	31%	18%	7%	10%
20% more	23%	18%	16%	34%	34%	7%	13%
10% more	30%	30%	22%	24%	28%	25%	37%
Uncertain	27%	42%	50%	10%	19%	60%	39%

* i.e., Phytophthora root and crown rot.

A visitor on a tour of a walnut orchard in Colusa County takes photographs. *Photo*: Evett Kilmartin.

respondents were willing to pay more than a 10% premium for rootstocks that are resistant to plant-parasitic nematodes, crown gall, and Phytophthora root and crown rot, as well as being drought tolerant. A majority (60%) of growers were uncertain about the premium they were willing to pay for resistance to blackline disease. The results were similar for root-knot and ring nematodes, considered less problematic on currently used rootstocks. However, growers were willing to pay higher premiums for resistance to crown gall, Phytophthora root and crown rot, and root lesion nematode/replant problems, all perceived as severe challenges.

The respondents' average WTP in table 2 was used to calculate the weighted WTP for each of the eight issues, weighted by each respondent's walnut acreage (table 3). These estimates are reflective of the market's potential to adopt the improved rootstocks because they consider the real impacts of growers with different farming scales. Clearly, crown gall, root lesion nematode, Phytophthora root and crown rot, and root lesion nematode/replant problems are recognized issues that led to the highest WTP by growers.

Results from the paper and online survey supported our hypothesis that walnut growers were concerned with production problems that include diseases and drought. The growers were highly interested in adopting advanced technologies such as new rootstocks to deal with problems, and they were willing to pay price premiums.

To validate the data collected from the online survey, four in-person phone interviews were conducted at the end of April 2022. Comparison of the survey and the interview results suggested a close alignment between them. For example, all interviewees confirmed that crown gall was among their top concerns in walnut production. It is interesting to note that some growers mentioned in the interview that they believed that no rootstock available in the current market was resistant to nematodes. They were looking forward to the development of such products in the future.

Past experiences with challenges

To deepen insights into grower attitudes, survey data were analyzed by econometric regression examining the *quantitative* impacts of growers' past experience on their interest in rootstock choices. In other words, if a grower had an issue with a particular walnut problem or expressed interest in a rootstock's resistance to that problem, what higher price would the grower be willing to pay?

A grower with only one problem may make different decisions than a grower who has to spread the budget for buying rootstocks among more than one of the seven problems that the survey addressed. In that case, the WTP for each of the rootstock features would be crowded out. Previous literature suggests that the existence of a crowding-out effect depends on the nature of the competing goals (Hansen and Andersen 2013). In this study, the survey data were used to empirically test whether the crowding-out effect occurred in walnut growers' decision-making in rootstock selection.

A complete econometric regression analysis for the above research question is included in the online technical appendix of this paper. The appendix includes details of the hypotheses testing, model building, and regression results. It also provides a more detailed review and discussion of the literature that indicates how this research relates to current literature.

Willing to pay for several traits

In these quantitative analyses, significant statistical evidence indicated three things. First, if a grower reported an issue with a particular problem, then the WTP for a rootstock's resistance to that problem increased by 9.5%. Second, compared with respondents who were "not interested in the advanced rootstock

TABLE 3. Weighted-average WTP for walnut rootstocks with resistance to soil-borne maladies (percent of growers)

	Root lesion nematode	Root knot nematode	Ring nematode	Crown gall	Root rot†	Blackline disease	Drought (tolerant)
Weighted average*	19%	11%	10%	23%	17%	8%	8%

* Note: the average is weighted by each respondent's acreage of walnut.
† i.e., Phytophthora root and crown rot.

feature," growers who were "very interested" would be willing to pay 18.2% more for it. Third, three variables — walnut production, years of farming, and education — have significantly positive impacts on a grower's WTP for the advanced features of the new rootstock.

On the other hand, the econometric results did not support the crowding-out effect in growers' WTP for rootstock features. Unlike crowding-out predictions, growers' WTP for an advanced rootstock attribute did *not* diminish with the co-existence of other walnut problems. The implication of this result is that budget may not be a binding limitation for growers when purchasing rootstocks. Growers seemed to consider the cost and benefits of each rootstock attribute *individually*. Thus, growers would decide their WTP for each rootstock attribute from the actual benefits that it brings to productivity and revenue, rather than trading off among different goals for budget purposes.

However, growers may still have to make trade-offs for other purposes. For example, if they have more than one pathogen in the field, then they would need to choose the rootstocks with resistance to the most serious disease problem. In addition, we need to be cautious about whether growers' willingness to pay for each trait can simply be added up for rootstocks with multiple beneficial traits, because that depends on whether the walnut maladies occur separately or tend to occur together. This requires further research. CA

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This project was supported by USDA-NIFA SCRI # 2018-51181-28437. On behalf of the research team, we would like to thank the following individuals for their guidance and support. Without their assistance, this project would not have been possible: Chuck Leslie; Joe Grant; Daniel Kluepfel; the Walnut Rootstock Advisory Panel (WRAP); Farm Advisors Janine Hasey, Luke Milliron, Katherine Jarvis-Shean, Mohamed Nouri, Kamyar Aram, Kari Arnold and Rachel Elkins; and Postdoctoral Researcher Elias Marvinney. The usual disclaimers apply.

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