RESEARCH ARTICLE

Strawberry growers are unlikely to forgo soil fumigation with disease-resistant cultivars alone

A UC survey found that disease resistant cultivars have not yet become a priority for strawberry growers, mainly because of economic pressures.

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Online: https://doi.org/10.3733/ca.2020a0021

Abstract

A major collaborative project launched in 2017 to accelerate the development of disease-resistant strawberry cultivars is responding urgently to two developments: increasing restrictions on fumigant use and the appearance of two novel pathogens not evidently manageable with allowed fumigants. As part of that project, I sought to understand the factors that guide growers' cultivar choice and assess their willingness to choose a pathogen-resistant cultivar to reduce or potentially replace fumigation. From a survey completed by 33 strawberry growers and in-depth interviews with 20 growers, I found that most growers prioritize yield in choosing cultivars, despite the industrywide problem with low prices. Few growers said they would be willing to substitute disease-resistant cultivars for fumigation without fail-safe disease control methods. Many growers, even those with existing organic programs, would opt for soilless systems in a tighter regulatory environment. This study thus suggests that disease resistance breeding must be coupled with support for other disease management techniques, and the economic situation that makes growers feel that they cannot forgo yield also needs attention.

Under the leadership of the UC Davis strawberry breeding team, with strong support from the California Strawberry Commission and several major strawberry shippers and nurseries, a major collaborative project was launched in September 2017. The overall objectives for the project are to identify natural sources of resistance to pathogens affecting strawberries and to accelerate the development of commercial cultivars resistant to a broad spectrum of soilborne and aboveground pathogens.

The urgency of this project, called the Next-Generation Disease Resistance Breeding and Management Solutions for Strawberry, stems from two developments. One is the increasing restrictions on the use of soil fumigants that have long been used to manage soilborne disease; the most reliably effective fumigant, methyl bromide, has finally been phased out except for nursery uses, in compliance with the international Montreal Protocol on Substances that Deplete the Ozone Layer, and other chemical fumigants, such as chloropicrin and 1,3-dichloropropene (brand name Telone), have seen more stringent application protocols,

Field day introducing new university-bred strawberry cultivars to stakeholders . A recent survey of California strawberry growers found that most prioritize yield over pathogen resistance when they select cultivars.

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such as larger buffer zones and township caps. The other development is increased disease pressure from two novel fungal pathogens, *Macrophomina phaseolina* and *Fusarium oxysporum* f. sp. *fragariae*, which colonize the plant, causing it to collapse and die.

The two developments are related. The virulence of the two novel fungal pathogens is widely believed to be associated with the end of methyl bromide use, since they began to appear in 2005 when growers started reducing the use of methyl bromide, even though they continued to fumigate with other chemicals, like chloropicrin (Koike et al. 2013; Lloyd and Gordon 2016; Tourte et al. 2016). While the extent of die-off from these two pathogens has yet to be documented, fears are increasing of significant production loss.

UC breeders started with disease resistance

UC has been developing strawberry cultivars since the 1940s, when UC scientists first identified the problem of *Verticillium* wilt. Although disease resistance was the original raison d'être of the program, breeders soon incorporated other qualities as well, such as yield, size, firmness and the ability to withstand freezing, for the frozen food market. Once fumigation became routine, disease resistance diminished as a priority (Darrow 1966; Wilhelm and Sagen 1974). Since that time, the UC breeding program has seen many changes; its varieties once comprised 95% of the plants sold (Wilhelm and Sagen 1974), but today it competes with private breeders, including Driscoll's, for the royalties from cultivar licenses.

UC varieties, nevertheless, remain very important, especially for growers who cannot or prefer not to pay the higher license fees for proprietary varieties (Baum 2005). Commonly used UC varieties, developed and patented before 2016, before the new breeding team came on board, include the day-neutral varieties Albion, Cabrillo, Monterey, Portola and San Andreas, which tend to be grown in the Pajaro Valley and Salinas regions, and the short-day varieties Benicia, Petaluma and Fronteras grown in the cooler months farther south in the Santa Maria/Guadalupe and Oxnard regions. Although some show mild resistance to disease, they were primarily bred for yield, size, color and firmness, with attention to flavor as well, especially in Albion.

Breeding for disease resistance has since returned as a high priority, which was recognized by the U.S. United States Department of Agriculture (USDA) in its decision to fund the UC project. The social science research I conducted is part of the project; I sought to understand the factors and institutions that guide growers' cultivar choice and assess their willingness to choose a pathogen-resistant cultivar to reduce or potentially replace the use of fumigation.

Grower perspectives collected

In collaboration with Professor Rachael Goodhue, Agricultural and Resource Economics, UC Davis, who was researching related questions, I initially opted to conduct a survey of growers. Developed in consultation with the key stakeholder group, the California Strawberry Commission, the survey was lengthy and complex. It mainly consisted of binary and multiple-choice questions useful for quantitative analysis, although it also solicited comments and open-ended responses that might be used in a qualitative analysis.

Written in both English and Spanish, the survey was administered in spring 2018 through the electronic platform Qualtrics (Qualtrics, Provo, UT) and by standard mail. In accordance with their policy of not sharing their mailing list, the commission distributed the surveys. They publicized in their newsletter an anonymous link to the Qualtrics version; an anonymous link collects no identifying information on responders, such as name or email, which therefore makes targeted follow-up impossible. In addition, they sent 236 surveys in the mail. We were unable to obtain information on the overlap of their newsletter and mailing lists.

The initial response to the survey was poor. Ten growers completed the mailed survey and none completed it online. Reasons that the response rate to our survey might have been particularly low include growers' skepticism about its intent, which may have been read as discouraging soil fumigation, their annoyance with the number of requests they are receiving from researchers and journalists — anecdotal reports from other social science researchers attest to strawberry growers being a difficult-to-contact research population — and annoyance with the length of the survey. However, there is additional evidence to suggest that the dissemination methods were not optimal. In our subsequent contact with growers at

Verticillium die-back in an experimental field.


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field days and by phone, many reported never having seen the surveys.

To augment participation, we called or emailed growers using contact information that I had obtained from publicly available sources in a prior research project (Guthman 2017). This yielded 21 online surveys and two additional mail surveys, all arriving within a few days. Altogether, we received 21 online surveys and 12 mail surveys, for a total of 33 surveys. I estimate this to be an 11% response rate, based on an estimate from California Strawberry Commission representatives that there were approximately 300 strawberry growers in California. If, however, the 236 hard copies initially sent out reflected the total grower population, the response rate would be 14%, closer to the 15% to 20% response rate social scientists consider good. It is difficult to confirm the number of strawberry growers through the Pesticide Use Reporting system, the typical source of grower contact information, because one operation can apply for multiple permits under various names.

Likely owing to the length of the survey, many of the surveys were incomplete and very few respondents provided qualitative data. With limited data to achieve my research objectives, especially to understand the nuances of growers' cultivar choices, I opted to augment the survey by conducting in-person interviews. Without access to contact information from the commission, I sought out growers who had participated in my prior project and who had welcomed additional follow-up. In constructing the sample, I emphasized growers who used UC varieties, to learn about breeding priorities, although not to the exclusion of growers who used proprietary cultivars, to understand the range of concerns and needs around cultivars. Since my goal for the interviews was to achieve depth rather than establish statistically significant patterns, a small sample was appropriate (Crouch and McKenzie 2006).

I was able to conduct interviews with 20 growers, 15 of whom grew nonproprietary varieties. All but six had some acres in organic production, although only one was a dedicated organic grower, growing multiple crops. The nature of this sample suggests a significant, but not surprising, overlap between those growers more generally willing to work with researchers and those experimenting with various production techniques. Importantly, many growers I attempted to contact were not reachable and/or had gone out of business, and even three of those I did interview had retired or all but exited strawberry production.

In the interviews, conducted in 2018 and 2019, I was able to reframe questions that had not quite worked in the surveys, as well as probe on the more difficult questions (Legard et al. 2003). Before completing them, I reached saturation, such that additional interviews were no longer producing more themes or deepening understanding, which substantiated that the sample size was sufficient (Hennink et al. 2016). Research assistants transcribed and coded interview data with NVivo qualitative research software (QSR International, Burlington, Mass.), identifying ideas and themes that further elucidated the more bounded questions asked in the survey.

Alongside these two primary sources of data (the survey and the interviews), I reviewed limited discussions about cultivars from my previous project and notes taken from short discussions with growers at field days and follow-up phone calls for the survey. These additional data were thoroughly in keeping with survey and interview data, providing further triangulation of the findings.

TABLE 1. Most important traits in strawberry cultivar

Trait	No. of responses
Yield	11
Marketability (appearance, size, taste)	7
Resistance to soilborne diseases	6
Long, steady yield relative to other available cultivars	4
Suitability to local conditions	4
Harvest timing (early)	3
Shipper requirements	2
Cost	1
Other	1
Total responses	**39**

TABLE 2. Cultivars planted for 2016 marketing year

Cultivar	No. of responses
Monterey	8
Cabrillo	8
Fronteras	6
San Andreas	4
Portola	4
Proprietary	4
Radiance	2
Albion	1
Other	1
Total responses	**38**

Growers emphasize yield

While the strawberry industry has long enjoyed the benefits of strawberries bred with multiple aims, emphasis in one area often comes at the expense of another (Darrow 1966). Since UC began its breeding program in the 1940s, growers have generally adopted those varieties with high productivity traits (Wilhelm and Sagen 1974). An important question, therefore, was within the current context of fumigant restrictions and the emergence of novel diseases, to what extent disease resistance had become a desirable trait. The survey thus queried growers about what traits they considered in choosing a cultivar. To prevent them from choosing all, it asked them for their top three priorities.

As seen in table 1, growers mostly wanted high yields, especially if a variation on the same theme, long steady yields, was included. While interest in resistance to soilborne diseases and in marketability (appearance, size, taste) were not negligible, they appeared as secondary priorities. These preferences were corroborated by answers to a question about which cultivars had been planted for the 2016 marketing year (table 2). Of the UC varieties, Cabrillo, Monterey and Fronteras were the most planted and they are high yield performers. In a recent trial involving equal plot sizes, Fronteras produced an average cumulative marketable fruit weight of 11,000 grams per plot, with Monterey producing close to 9,500 per plot. Of these two cultivars, Monterey allegedly has better flavor. San Andreas, the next most widely planted cultivar, is most associated with Fusarium resistance, but in that same experiment yielded only a little over 7,000 grams per plot. The notably flavorful Albion, which is popular among growers selling in farmers markets, although was not often planted by survey respondents (table 2), yielded only about 6,500 grams per plot (Cole et al. 2018).

Answers to a third question further clarified the dimensions of the trade-off between yield and disease resistance. Asked about the maximum decline in yield a grower would accept in a cultivar with high levels of resistance to soilborne diseases and no change in production costs, most growers reported that no or only a minimal yield decline was acceptable (table 3).

Qualitative responses and interviews provided additional evidence that growers tended to choose yield over pathogen resistance and helped clarify their rationale. Of the 20 growers interviewed, 15 said yield was a high priority, albeit not without some hedging. Many recognized the importance of marketability characteristics, acknowledging that a strawberry that lacks flavor, for example, would turn off consumers. For that reason, they were more likely to grow Monterey than even higher yielding varieties, and some shippers insisted that they grow a marketable variety such as Monterey.

Growers who use proprietary varieties because they sell to shippers who require them to (Driscoll's and WellPict) have somewhat less choice in what they grow. The shipper sets priorities, and Driscoll's, in particular, has allegedly prioritized flavor and disease resistance over yield in their breeding. Growers who favor working with these shippers do so because they obtain higher prices, making up for the loss of yield. Still, my interview data showed that when given a choice these growers, too, favor yield, especially because they are paid the same no matter what they grow.

When I pressed on questions of why yield remained a priority for those selling in wholesale markets when they also complained of low prices, I learned of a significant collective action problem. Most growers recognized that it made sense for the industry to reduce supply but felt that it was folly personally to choose a lower-yielding variety. This is the technological treadmill problem first identified by agricultural economist Willard Cochrane in 1958.

Cochrane noted the tendency of farmers to adopt technologies that reduce costs because early adopters make additional profits as their expenses decline (Cochrane 1958). As he also noted, such tendencies eventually negatively affect crop prices because other farmers join in, supply increases overall and price competition ensues, driving some out of business. In the case of adoption of a higher-yielding variety, rather than reducing cost, the output increases with little additional effort, making such a strategy nearly irresistible. As one grower put it, "We're in a competitive environment. We like to say we don't grow a commodity, but there are commodity-like characteristics. So if you have a variety and neighbor selling into same market, if he's more productive he will have an edge."

In addition to low prices, fixed costs such as land leases and land preparation are extremely high and increasing in strawberry production. Labor costs, though variable, have risen considerably with labor shortages and new minimum wage and overtime laws. Therefore, growers feel they need to sell as many berries as they can to be economically viable. As another grower said, "You could have the best fruit around, but if you don't have yield you can never make any money. . . . I mean our costs are going through the roof. The only way we can bring some of the costs down is through yield."

TABLE 3. Acceptable decline in yield for a cultivar with high levels of disease resistance

Acceptable level of decline	No. of responses
0%	3
1–5%	5
6–10%	2
11–15%	0
15–20%	1
More than 20%	1
Total responses	**12**

At the same time, growers also questioned this logic, asserting that the industry was undermining itself by continuing to breed and grow ever more high-yielding varieties: "So we want these varieties to give out more numbers and last longer, but it's hurting us in the long run. . . . It seems like people think that if I plant 100 acres and make such amount of dollars, if I put 200 acres in, I'm going to make double that, but it doesn't work that way." This observation is corroborated by the most recent statistics on historical trends reported by the USDA National Agricultural Statistics Service. Utilized production of strawberries (i.e., the volume of marketed strawberries) grown in California increased from 539 million pounds in 1974 to 3,015 million pounds in 2012, an increase of 559%; grower prices increased only from 29 cents per pound to 80 cents per pound, an increase of 276%, in that same time period (USDA NASS 2013).

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It is not that growers were oblivious to the need for disease resistance, but some were making a calculated decision that the yield benefits of a cultivar outweighed the risk of plant loss. As one grower said, "We can have 30% die out of Radiance (in Mexico) due to soilborne pathogens and still beat the yield on San Andreas." More often, growers had not experienced enough plant loss to make disease resistance a priority: "If we begin to see more Vert or other pathogens, we will worry more. Right now, all is cool."

Several growers emphasized the need to know the soil history to determine what cultivar to grow. Some growers, though, who had experienced disease loss were more inclined to let go of leases on diseased land than give up on the yield or marketability advantages of a cultivar. There were exceptions, too. One grower spoke of having planted Monterey and losing 40% of the plants one year. After that, he "switched soils," but that soil was infested too, and he lost 32% of Monterey that year. He then turned to growing almost entirely San Andreas. Not surprisingly, it was growers with organic fields who were most interested in disease-resistant varieties. With fumigation still available, growers with conventional fields remained relatively uninterested in these varieties.

Growers reluctant to forgo fumigation

Understanding that most growers were unwilling to trade off yield for pathogen resistance because soil fumigants were available, I wanted to explore in more depth what role pathogen-resistant cultivars could play in reducing the use of soil fumigation. The survey included two questions about what prevents growers from reducing their use of preplant soil fumigation and what currently encourages them to reduce their use of preplant soil fumigation. It asked them to choose all answers that applied.

TABLE 4. Conditions that prevent reduction of preplant soil fumigation

Conditions discouraging reduction	No. of responses
Crop loss/potential crop loss	13
Lack of disease-resistant cultivars	10
Lack of profitable alternative technologies (e.g., hydroponics, substrate/soil substitute, anaerobic soil disinfestation)	6
Lease requirements	5
Lack of support/information regarding alternative technologies	4
Shipper or retailer requirements	2
Total responses	**40**

TABLE 5. Conditions that encourage reduction of preplant fumigation

Conditions encouraging reduction	No. of responses
Proximity to housing or schools outside buffer zones	10
Existing regulations/label restrictions/use permit conditions (including buffer zones)	9
Possibility of new regulations	8
Access to land with low disease pressure (owned or leased)	5
Public pressure	3
Concern with public health	3
Organic price premium	2
Other	1
Total responses	**41**

Answers to these questions aligned with previous studies and reports (Guthman 2017; Lloyd and Gordon 2016; Tourte et al. 2016). Growers most often chose "crop loss/potential crop loss" as the condition that prevented them from reducing their use of preplant fumigation (table 4). Buyer and lease conditions played a role, as well — for instance, some leases require that growers fumigate so that the lessors, often vegetable growers, get the benefits of fumigation. On the flip side, regulatory pressures, including restrictions on fumigation in the form of buffer zones, were most encouraging growers to reduce fumigation, with opportunities such as entry into organics or land with low disease pressure (e.g., previous pasture) also playing roles (table 5).

Qualitative responses and interviews corroborated and nuanced the latter answers. Several growers emphasized how fumigant restrictions had pushed them to find alternative means to grow strawberries and discussed organic certification and the accompanying price premium as a way of offsetting the potential costs and crop losses of forgoing fumigation. In these instances, they saw disease-resistant varieties as enabling such a transition: "Without disease-resistant varieties, conventional strawberries require the use of fumigants. If they become unavailable, organic is the best alternative." The trade-off is noteworthy given that growers have to give up other pesticides besides fumigants to be certified organic.

A few growers mentioned their willingness to give up fumigation without converting to organics, simply because of fumigation costs. And a few growers noted that organic prices might be too weak to make that trade-off. One wrote in the survey, "If I were organic [I'd reduce fumigation use], but they don't have the price either right now." Even the many interviewees who have organic programs were not at this time considering transitioning their entire operation; instead, they were choosing fields for their organic programs where soil conditions make them viable, often areas with low disease pressure.

That organic markets were nevertheless the main factor incentivizing fumigant reduction was confirmed by answers to a question about whether there were any conditions in which growers would consider eliminating the use of preplant soil fumigation, not including transitioning to organic. Only 10 growers replied to this question, but seven said no, with two maybes and one yes. When asked to comment about what, if any, conditions might lead growers to eliminate preplant soil fumigation altogether within the next 5 years, surveyed growers mentioned cultivars completely resistant to all major soilborne diseases — not just simply tolerant to diseases, which is what the best cultivars are today.

Growers basically wanted alternatives that wouldn't forgo yield, quality or higher profit — in other words, something foolproof. In an interview, one grower was emphatic on this point: "It has to be proven to me, I gotta see it. . . . But I'm not going to do it because [the UC breeder] says 'Oh, by the way, I have this variety that's resistant to *Macrophomina*, you don't need to fume.' Well, let me see that, you know what I mean?"

The more personalized setting of the interviews also allowed me to explore what growers would do if fumigants were taken away. Here I learned that while such a possibility heightened interest in disease-resistant varieties, several said that they would leave strawberries or retire early, and many said they would move to soilless regimes. As it happens, one of the challenges of soilless systems is finding cultivars that work in those settings. The performance of existing varieties is reportedly subpar.

Those interested in remaining "on ground" clarified that disease-resistant varieties would be helpful, but they would need to adopt other tools as well, such as nonchemical modes of soil disinfestation, making breeding for disease resistance only a partial solution.

One grower said, "Just having a variety that is tolerant of x, y or z only does so much. . . . . That would be just like added insurance."

Several growers noted the long pipeline to the development of good varietals, because of the lengthy time needed for testing and propagation. Some were also aware of the difficulty in breeding for multiple diseases and were skeptical that a truly disease-resistant variety could be developed. Some growers even suggested that industry and ecological conditions might be too dynamic for cultivars bred for specific conditions to be of use by the time they are developed.

The last survey question asked about the policies or practices that would encourage planting of a disease-resistant cultivar instead of fumigating and asked respondents to choose all answers that applied. Here again it appeared that additional regulatory restrictions would increase interest in disease-resistant cultivars (table 6), although it was clear that few growers would wish for such a situation. Were it to come about, support from UC Cooperative Extension could help aid the transition, as could financial support in terms of higher prices or subsidies. As of now, however, with fumigation still allowed, albeit restricted, most growers were concerned with other challenges: "To be honest, right now our focus is definitely in other factors. If the economics don't work, we can have the disease-resistant variety but we're not going to be able to farm it."

Is disease resistance a priority?

Overall, while there was still keen interest in seeing disease-resistant cultivars developed, disease resistance has become less of a priority for growers, mainly because other pressures have overtaken concerns with disease. It is also clear that disease-resistant varieties alone are unlikely to replace fumigation or, more to the point, convince growers to take the risks of reducing or forgoing fumigation.

As emphasized in a report issued by the California Department of Pesticide Regulation (DPR 2013) encouraging research into fumigation alternatives, without the magic bullet of chemical fumigation, disease management is more complex, and strawberry growers would need to incorporate a combination of complementary methods and technologies to address the changing economic, ecological and regulatory environment of strawberry production (also Lloyd and Gordon 2016). These complementary methods need continuing research support and testing in combination with each other. Consideration should also be given to ways of mitigating the costs of growing berries in this ever more challenging economic environment.

Does that mean breeders should turn to other priorities than disease resistance? Not at all. Regulation is unlikely to become less restrictive or pathogens less virulent, and at some point disease resistance will become imperative. Given the difficulty of breeding effectively for all desirable traits, it is arguable breeders should even double down on disease resistance and lighten up on yield. Although growers want yield, breeders responding to that are perpetuating the technology treadmill that contributes to low prices. Indeed, it is important that super-industry forces, those whose interests surpass those of individual growers, including university scientists, shippers and policy makers, aim to curb this prioritizing of yield by attending to the economic exigencies that make yield so important for growers. CA

TABLE 6. Factors that would encourage use of disease-resistant cultivars over fumigation

Factors encouraging disease-resistant cultivars	No. of reponses
Tighter restrictions on fumigants	8
Higher prices from buyers	6
Information from UC Cooperative Extension advisor or other UC personnel	5
Availability of data on cultivar yield when pathogens are present at different levels	4
None	3
Information from Cal Poly	2
Crop insurance against disease outbreaks	2
Direct cash subsidy	2
Subsidized field trial on farm	2
Other cost support	1
Total responses	**35**

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She wishes to thank Rachael Goodhue for collaboration on the initial survey and Madison Barbour, Madeleine Corich, Daniel Tregeagle and Erica Zurawski for research assistance at various phases of the project. Research was supported by the USDA NIFA program, award #2017-51181-26833.

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