An Economic and Pest Management Evaluation of Pyrethroid Insecticides in California Agriculture

Prepared by the California Department of Food and Agriculture's Office of Pesticide Consultation and Analysis, and the University of California, Davis

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Executive Summary

This report provides a discussion of the role of pyrethroid insecticides in pest management and an estimate of the economic impacts should pyrethroid use become unavailable. While there is no imminent regulatory action regarding pyrethroid use in California, the goal of this report is to project the possible economic and pest management implications should all pyrethroids become immediately unavailable in order to inform future policies. We analyze nine focal crops: alfalfa, almond, celery, citrus, cotton, peach, pistachio, strawberry, and tomato. Citrus includes orange, grapefruit, lemon, lime, tangerine and hybrids, and pomelo. We present the costs separately for fresh and processing tomatoes. Crops were chosen based on their use of pyrethroids relative to their harvested acreage, their use relative to other crops, and their economic importance to California agriculture.

These nine crops accounted for 71.7% of statewide pyrethroid use and 32.6% of the value of California's agricultural production in 2022.

Among the nine crops considered, the estimated increase in pest management costs ranges from $0.81 million per year to $53.41 million per year, depending on the crop and base year considered (Table ES-1). Given the length of this report, crops are separated by chapter and can be read individually.

Table ES-1: Estimated Increase in Pyrethroids-Related Pest Management Costs by Crop and Year ($ Million)

Crop	2020	2021	2022	Average Total Annual Cost
Alfalfa	$11.03	$8.85	$8.73	$9.54
Almond	$53.41	$45.58	$43.93	$47.64
Celery	$1.66	$1.46	$1.52	$1.55
Citrus	$6.73	$6.00	$6.96	$6.56
Cotton	$5.06	$3.44	$3.67	$4.06
Peach	$3.33	$3.24	$3.24	$3.27
Pistachio	$32.59	$34.42	$35.11	$34.04
Strawberry	$1.08	$0.81	$0.99	$0.96
Tomato, Fresh	$1.20	$1.44	$1.44	$1.36
Tomato, Processing	$4.44	$4.84	$5.42	$4.90

Note: Totals may not add up due to rounding.

Methods used in this paper, including the use of the Pesticide Use Reports database, follow Steggall et al. (2018). We estimate the cost of losing access to pyrethroids by comparing the cost of managing target pests with pyrethroids versus non-pyrethroid alternative AIs. These estimates are presented in Table ES-1.

Table ES-2: Estimated Per-Acre Pest Management Material Costs with and without Pyrethroids by Crop

Crop	Pyrethroid Cost ($)	Composite Alternative Cost ($)	Percent Difference in 2022
Alfalfa	$2.34	$23.24	893.0%
Almond	$11.92	$46.18	287.4%
Celery	$8.37	$38.43	359.4%
Citrus	$21.87	$53.44	144.3%
Cotton	$6.36	$25.09	294.7%
Peach	$5.88	$50.69	762.0%
Pistachio	$12.52	$46.65	272.6%
Strawberry	$36.86	$48.14	30.6%
Tomato, Fresh	$8.24	$32.06	289.3%
Tomato, Processing	$7.21	$27.48	280.9%

Table ES-2 summarizes the per-acre costs of insecticide products in a pyrethroid-related pest management program (status quo), an alternative program, and the percent difference between these costs in 2022. Pyrethroid costs range from $2.34 per-acre to $36.86 per-acre, while alternative management costs range from $23.24 per-acre to $53.44 per-acre. Percent differences range from 30.6% to 893.0%. Notably, given that pyrethroid costs are so low, the proportional impact on material costs for using alternatives can be quite large. Full analyses of these costs and additional caveats are presented in the full text.

Table ES-3: Estimated Gross Revenue Losses for Almond, Pistachio, and Strawberry by Year: Perfectly Elastic Demand ($ Millions)

Crop	2020	2021	2022	Annual Average	Change (%)
Almond	$247.18	$275.53	$263.11	$261.94	-11.5
Pistachio	$290.63	$325.21	$324.86	$313.57	-19.1
Strawberry	$223.53	$211.12	$258.37	$231.01	-15.0

In the absence of pyrethroids, yield losses would be anticipated for three of the focal crops. Table ES-3 summarizes the changes in gross revenues for almond, pistachio, and strawberry due to yield loss. These three crops are anticipated to experience yield loss if pyrethroids are unavailable, as no effective management strategies for leaffooted bugs (almond and pistachio) or lygus bugs (strawberry) currently exist outside of pyrethroids. Projected yield losses are 11.5% for almond, 19.1% for pistachio, and 15.0% for strawberry, corresponding to gross revenue losses ranging from $211.12 million to $325.21 million. Future development and registration of effective alternatives could mitigate yield loss. Other commodities are not included as yield loss is not expected under alternative management.

Alfalfa. Common pests in alfalfa managed with pyrethroids include alfalfa weevil, aphid, grasshopper, leafhopper and hopper, cutworm, armyworm, alfalfa caterpillar, webworm, pale-striped flea beetle, and lygus bugs. Monthly pyrethroid use in alfalfa peaks in March. The associated average total annual cost increase of replacing pyrethroids with alternatives is $9.54 million, or 0.7% of the 2022 value of production.

Almond. Common pests in almond managed with pyrethroids include leaffooted bugs, stink busg, navel orangeworm (NOW), and peach twig borer. Monthly pyrethroid use in almond peaks in July to target NOW during almond hull-split. The associated average total annual cost increase is $47.64 million. Additionally, yield losses of 11.5% are projected from the inability to effectively control leaffooted bugs if pyrethroids are unavailable, resulting in an average annual decline of $261.94 million in gross revenues. Overall, the estimated annual average reduction in net returns is $309.58 million, representing 5.8% of the 2022 value of production.

Celery. Common pests in celery managed with pyrethroids include beet armyworm, cutworm, leafminer, aphids, and lygus bugs. Monthly pyrethroid use in celery peaks in September. The associated average total annual cost increase is $1.55 million, or 0.3% of the 2022 value of production.

Citrus. Common pests in citrus managed with pyrethroids include Asian citrus psyllid (ACP), forktailed bush katydid, European earwig, southern fire ant, leaffooted bugs, Fuller rose beetle, and glassy-winged sharpshooter. Monthly pyrethroid use in citrus peaks in January to control for ACP and May to control for earwigs and katydids. The associated average total annual cost increase is $6.56 million, or 0.2% of the 2022 value of production.

Cotton. Common pests in cotton managed with pyrethroids include lygus bugs, silverleaf whitefly, beet armyworm, darkling beetle, and false chinch bugs. Monthly pyrethroid use in cotton peaks between June and August. The associated average total annual cost increase is $4.06 million, or 0.9% the 2022 value of production.

Peach. Common pests in peach managed with pyrethroids include peach twig borer, oriental fruit moth, leafroller, tree borer, and plant bugs. Monthly pyrethroid use in peach peaks in January to control for dormant peach twig borer. The associated average total annual cost increase is $3.27 million, or 0.5% of the 2022 value of production.

Pistachio. Common pests in pistachio managed with pyrethroids include navel orangeworm, leaffooted bugs, stink bugs, and small plant bugs. Monthly pyrethroid use in peach peaks between May and August. The associated average total annual cost increase is $34.04 million. Additionally, yield losses of 19.1% are projected from the inability to control leaffooted bugs if pyrethroids are unavailable, resulting in an average annual decline of $313.57 million in gross revenues. Overall, the estimated annual average reduction in net returns is $347.61 million, representing 14.5% of the 2022 value of production.

Strawberry. Common pests in strawberry managed with pyrethroids include lygus bugs, spotted wing drosophila, thrips, aphid, whitefly, lepidopteran larvae, root weevil and grub, garden symphylan, and mites. Monthly pyrethroid use in strawberry peaks between May and June in Southern California, and peaks between July and September in the Central Coast. The associated average total annual cost increase is $0.96 million, or 0.03% of the 2022 production value. Additionally, yield losses of 15% are projected from inability to control lygus bugs if pyrethroids are unavailable, resulting in an average annual decline of $231.01 million in gross revenues. Overall, the estimated annual average reduction in net returns is $231.97 million, representing 7.8% of the 2022 value of production.

Tomato. Common pests in tomato managed with pyrethroids include lepidopteran larvae, stink bugs, aphid, flea beetle, lygus, thrips, whitefly, garden symphylan, false chinch bug, beet leafhopper, and leafminer. Monthly pyrethroid use in tomato peaks in July. The associated average total annual cost increase for fresh tomato is $1.36 million, or 0.5% of the 2022 value of production. The associated total annual cost increase for processing tomato is $4.90 million, or 0.4% of the 2022 value of production.

Caveats. There are several caveats regarding the estimates in this paper. We consider historical data and the impacts of pyrethroids loss during this time. However, changes in crop acreage or pesticide use patterns since this time may impact the accuracy of our results. A number of external factors (e.g., land allocation, additional pesticide regulations, new AIs) could also alter the estimated costs. Another caveat is that we do not analyze all applications of pyrethroids; instead we limit our analysis to the crops that are the highest users of pyrethroids. As such, our presented estimates are not the full cost to California agriculture as a complete sector. Moreover, costs are not borne equally by all acreage.

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Introduction

Pyrethroid insecticides are synthetic derivatives of pyrethrins, a group of naturally derived compounds produced by chrysanthemum flowers. The first pyrethroid, allethrin, was made available for commercial use in the US during the 1950s. Since then, over 30 pyrethroids have been developed for agricultural and residential use (Matsuo, 2019). Pyrethroids currently represent over 25% of the global insecticide market, due to their broad-spectrum insecticidal activity, low mammalian toxicity, and low cost (Gajendiran and Abraham, 2018). In California, they are used in the production of a wide range of field and orchard crops, area-wide vector control programs, and residential pest control. As shown in Figure 1, pyrethroid use grew significantly in California from 2002 until 2018, when it peaked. By 2022, the acreage treated with pyrethroids had declined 16.4% from 2018. Over the past two decades, the U.S. Environmental Protection Agency (EPA) and the California Department of Pesticide Regulation (DPR) have periodically reevaluated the ecological and human-health risks of pyrethroid use, leading to updated federal and state regulations aimed primarily at reducing surface water contamination.

This report addresses the role of pyrethroids in California agriculture and provides an estimate of the economic and pest-management effects should they become unavailable for nine crops: alfalfa, almond, celery, citrus, cotton, peach, pistachio, strawberry, and tomato. There is no imminent regulatory action proposed regarding use of pyrethroid insecticides; this report aims to serve as an informational resource on the state of agricultural pyrethroid use to inform the development of future policies.

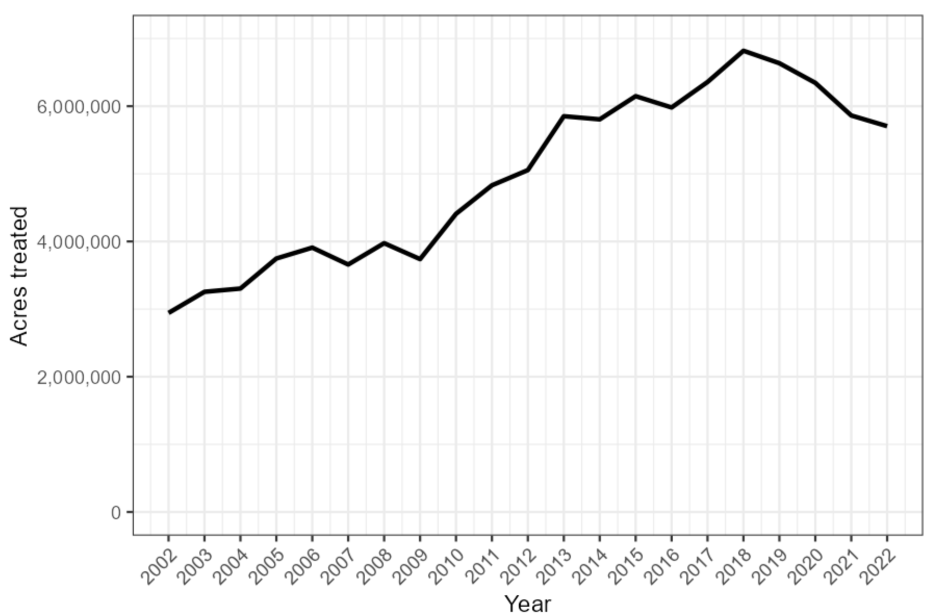


Figure 1: Acres Treated Statewide with Pyrethroids: 2002–2022

Regulatory Background

In general, pesticides are regulated at the federal, state and local levels. For pyrethroids, relevant regulations are at the federal and state levels.

US EPA The United States Environmental Protection Agency (US EPA) is responsible for regulating pesticide use within the US. In 2008, US EPA completed "Reregistration Eligibility Decisions (REDs)" for pyrethrins, seven pyrethroids (allethrins, cypermethrin, tau-fluvalinate, permethrin, resmethrin, sumithrin (d-phenothrin), tetramethrin), and two synergists (MGK-264, piperonyl butoxide). As part of the REDs, US EPA required mitigation measures to reduce risk associated with human and ecological health concerns. Pyrethroid registrants were required to update the spray drift language on agricultural product labels to be compatible with FIFRA (US EPA (2008)). Additionally, in response to water quality concerns arising from residential use of pyrethroid and pyrethrin products, US EPA implemented the "Environmental Hazard and General Labeling for Pyrethroid and Synergized Pyrethrins Non-Agricultural Outdoor Products" initiative in 2009 (revised in 2013). The initiative aimed to reduce the potential for pesticide runoff and drift. In 2009, US EPA conducted "A Review of the Relationship between Pyrethrins, Pyrethroid Exposure and Asthma and Allergies," but found no evident pattern of an association between pyrethrins/pyrethroid exposure and asthma and allergies. As a result, no regulatory actions (e.g. new label statements) were required (US EPA (2009)). The 2011 "Pyrethrins/Pyrethroid Cumulative Risk Assessment" found that there are no risk exposure concerns from current uses of pyrethrins and pyrethroids after the 2008 mitigation measures were in place (US EPA (2011)).

In 2016 US EPA released a "Draft Ecological Risk Assessment" for pyrethrins and given pyrethroids (bifenthrin, cypermethrin, cyfluthrins, deltamethrin, esfenvalerate, fenpropathrin, cyhalothrins, permethrin) to inform mitigation, and regulatory decisions for pyrethroid registration reviews, and a "Risk Management Rationale" to justify their methods and conclusions. Consistent risk was identified for aquatic organisms, with substantial evidence of high levels of pyrethroids and pyrethrins in waterways. Risk to mammals and birds, while identified in previous assessments, was found to be low. Throughout 2016–2018, US EPA released draft "Human Health Risk Assessments," for individual pyrethroids. Most recently in November 2019, EPA released "Proposed Interim Registration Review Decisions (PID)" for five pyrethroids (cyphenothrin, imiprothrin, tetramethrin, flumethrin, momfluorothrin); PIDs determine whether a given pesticide continues to, or does not, meet standards set in FIFRA and may also require mitigation measures. US EPA also released its "Pyrethroids and Pyrethrins Revised Ecological Risk Mitigation Proposal for 23 Chemicals" (US EPA (2020)), of which 16 chemicals are labeled for agricultural use. To address risks of concern for aquatic invertebrates, US EPA proposes an increase in vegetative filter strips (not applicable to western irrigated agriculture, incl. CA) and updates to spray drift mitigation language and spray drift buffer requirements. It also proposes mitigations to minimize exposure risk to pollinators. EPA's recent reevaluation of the "Food Quality Protection Act (FQPA) safety factor" for pyrethroids also proposes that decreasing the safety factor (from 10x to 3x) will still protect the health of infants and children (US EPA (2019)).

DPR The Department of Pesticide Regulation (DPR), part of California's Environmental Protection Agency, is the state's designated authority for regulating pesticide registration, sale and use. DPR is mandated to conduct continuous evaluation and reevaluation of all registered pesticide products based on information from government agencies and the public. In 2006, following monitoring and toxicity assessments that revealed widespread presence of synthetic pyrethroid residues in the state's waterways at levels toxic to indicator species, DPR commenced the reevaluation of 608 pyrethroid-containing pesticide products (manufactured by a total of 123 registrants). DPR determined that restricting outdoor residential use of pyrethroids represented the best opportunity to limit runoff. Accordingly, it established regulations limiting when and how pest control businesses can apply certain pyrethroids in 2012 (3 CCR § 6970). In 2014, DPR released a "Final Decision Concerning Reevaluation of Certain Pyrethroid Pesticide Products" which concluded the reevaluation initiated in 2006 (CDPR, 2014). DPR determined that no additional mitigation of pyrethroid use—beyond the 2012 residential use restriction— was necessary at that time. It is possible that further pyrethroid regulation will be implemented due to continued detection of high levels of pyrethroids in surface waters, especially in the Central Coast and Central Valley regions (State Water Resources Control Board, CalEPA, 2022). Cyfluthrin has been under reevaluation for many years, which may result in possible mitigation measures pending an ongoing human health risk assessment (CDPR, 2025b).

Role of Pyrethroids in Integrated Pest Management

AB 2113 passed in 2024, establishing the following definition of Integrated Pest Management in California's Food and Agricultural Code:

> An ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and nontarget organisms, and the environment.

This section discusses the role of pyrethroid pesticides in California IPM strategies and the potential effects of removing pyrethroids from use.

Non-target broad-spectrum activity Pyrethroid insecticides are widely used due to their low cost and broad-spectrum activity against many pest species. However, pyrethroids have often been replaced by other types of controls in IPM programs because this broad-spectrum activity can kill natural enemies that would have otherwise provided biological control. While effective initially, the use of broad-spectrum materials can lead to secondary pest outbreaks and the development of resistance in both target and non-target arthropod species (Pu and Chung, 2024). For these reasons, they are mainly used as a rapid response for outbreaks, as rotational active ingredients (AIs) to slow the development of resistance for other materials, as a synergist with another insecticide that enhances the efficiency of both, and as part of revamped pest management programs implemented after regulations have removed or restricted other AIs due to impacts on human health or the environment.

The indirect effects of pyrethroid unavailability on the effectiveness of biological control and resulting levels of insecticide use across systems are difficult to predict accurately. Their precise effects on insect communities can be influenced by the time of year, location, and cumulative impact of chemicals applied to manage other pests (Cloyd, 2012). Pest resurgences or secondary pest outbreaks are well-documented effects sometimes following pyrethroid applications in various crops.

Alternative insecticides that have a more limited spectrum of activity against other taxa do not have the residual activity of pyrethroids and are less likely to result in pest resurgence or secondary pest outbreaks. Trade-offs between the benefits and costs of using broad-spectrum materials are a critical consideration in the selection of materials for pest management. However, pyrethroids' effects on non-target species are not directly considered in this report.

Resistance management Repeated applications of insecticides with the same modes of action creates selection pressure on resident insect populations that can lead to reduced efficacy or control failures. Without careful planning and use, individuals that survive insecticide treatments can reproduce and generate large populations of pests resistant to specific insecticides or classes of insecticides . Where limited cultural, biological, and chemical control options exist, resistant pest populations can cause substantial damage to agricultural production and further worsen resistance as management tools disappear. Managing the development of resistance is thus an integral component of any pest management plan (Onstad and Knolhoff, 2022).

When sprays are deemed necessary, the primary practice of resistance management is rotating AIs with different modes of action. Many of the alternative insecticides discussed in this report have activity against specific taxonomic groups of pest (e.g., lepidopteran larvae, hemipteran insects). This limits their effects on non-target organisms, but can lead to resistance in the target group if used repeatedly within a season. Through their broad-spectrum activity, pyrethroids can provide significant value to IPM programs by serving as a rotational AI in-between applications of more pest-specific materials. Restricting the use of pyrethroids may leave producers with fewer options for resistance management and accelerate the development of resistance to newer, selective materials.

Methods and Data

Methods follow Steggall et al. (2018). The criteria used for crop selection are discussed first, followed by the data regarding pesticide use, the integrated pest management (IPM) methods addressed, and the components of the economic analysis.

Focal Crop Selection

The nine crops addressed fall into two categories: those with high acreage and high total pyrethroid use, and those with more limited acreage that are threatened by specific pests controlled primarily with pyrethroids. Figure 2 presents total pyrethroid use for the focal crops. Our goal is to provide a view of pyrethroids' roles in both broad swaths of California agricultural acreage and critical use cases in specialty commodities. Due to the diversity of the selected crops, the analysis also incidentally addresses a geographical range of production regions.

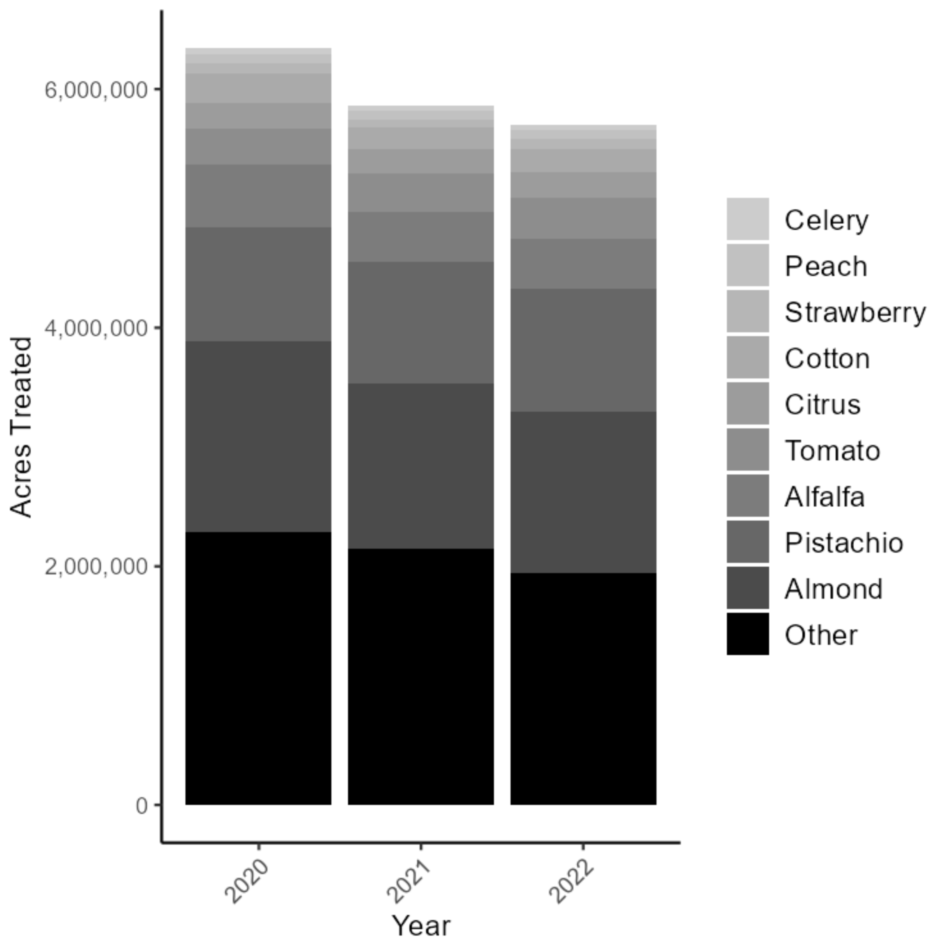


Figure 2: Acres Treated Statewide with Pyrethroids by Crop: 2020–2022

Pesticide Use Data

We obtained the amount of AI applied and treated acreage from the Pesticide Use Reports (PUR) database for pyrethroids and alternative AIs from 2020 to 2022, the most recent three years available at the time. There may have been substantial changes in use or availability of AIs since then which are not captured here. All agricultural pyrethroid and alternative AI applications to the focal crops were included in our analysis.

IPM Overview

Identifying pyrethroid alternatives requires knowledge of which pests growers are generally targeting with pyrethroids and which alternative AIs may be effective for a given crop-pest combination. However, the PUR database does not include information about the target pest(s). Therefore, we rely on consultations with pest control advisors, growers, industry members, University of California Cooperative Extension personnel, and our own experts to identify all pyrethroids used in each focal crop and the pests they target. We then determine all available alternative AIs that could similarly control those target pests.

Economic Analysis

In order to estimate the cost of a hypothetical scenario in which pyrethroids become unavailable, we compare the cost of managing the target pests with and without pyrethroids. To evaluate the latter, for each crop we construct a composite alternative of what growers would apply if pyrethroids were unavailable. The composite alternative is a weighted average of the use of each alternative AI, where the weights are shares of total acreage treated over the 2020–2022 period with any AI considered an alternative to pyrethroids. For each crop we identified a representative pesticide product for each AI to use when determining the cost of not using pyrethroids. In most instances, the representative product was the one applied to the most acres of that crop in the 2020–2022 study period. However in situations where the most used product is mixed with pyrethroids or is no longer registered, the second most applied product was used. Specific product substitutions are described in the Economic Analysis sections for each crop. Product prices were collected from online retailers, agricultural product vendors, academic researchers, manufacturers, and growers with the agreement that they would remain anonymous.

The economic analysis uses a partial budgeting approach, meaning we consider only changes in costs and revenues due to using an alternative AI rather than a pyrethroid. Using application rates and the representative product prices we calculate the cost per acre of each AI. We then construct the cost of the composite alternative per acre. We identify the affected acreage as all acreage treated with pyrethroids during the study period and compare the cost of treating with a pyrethroid to the counterfactual of treating with alternatives. The annual cost of not using pyrethroids is calculated by subtracting the total cost of using pyrethroids from what the total cost of using alternative AIs on the acreage treated with pyrethroids would have been in 2020–2022.

Caveats

There are several caveats regarding the estimates presented here. They can be grouped into three broad groups: methodology, external factors not included in the analysis, and biological changes. Steggall et al. (2018) document the development of the methodology, the factors underlying each major modeling decision and resulting major caveats.

Methodologically, one consideration is that we use historical data. To the extent that there have been significant changes in pesticide use patterns since then, there is the possibility that affected acreage is significantly different from the historical record. Another is that we do not analyze all applications of pyrethroids, instead limiting consideration to crops that are major users. Hence, the estimates are not the full cost to California agriculture as a complete sector.

There are a number of external factors that could materially alter the results. Growers may change their land allocation choices across crops, which could change pesticide use patterns. New pesticide use regulations may alter the availability of AIs that are alternatives for pyrethroids. Cancellations of specific uses or restrictions on use, such as permitted application methods or rates could affect the availability of alternative AIs. One such example is the set of restrictions placed on the use of nitroguanidine-substituted neonicotinoid insecticides (NGNs). These regulations came into effect in January 2024, thus their effects on insecticide use patterns are not captured in this report. OPCA has previously published analyses examining the potential effects of those regulations (Goodhue et al., 2020). On the other hand, it is possible that new uses of existing AIs or new AIs could be approved for use in California.

An important biological consideration is the development of insecticide resistance. Resistance management requires rotating AIs with different modes of action, and the loss of any AIs can accelerate the development of resistance. When resistance occurs, growers may use additional insecticide applications or different products, which would affect management costs. Invasive species are another biological consideration; when novel pest species enter a system, management practices can shift dramatically.

Alfalfa

California accounts for approximately 7.1% of U.S. alfalfa production and 19.2% of total U.S. alfalfa exports. In 2022 there were approximately 450,000 acres of alfalfa harvested for hay, 490,000 acres for forage, and 50,000 acres for haylage and greenchop. Production value is up by approximately 32.9% from 2021, with total value of $1.43 billion in 2022. This increase is largely due to an increase in the price per ton of alfalfa hay. Alfalfa was the state's tenth largest agricultural commodity by production value (CDFA, 2023a).

The two largest producing counties in California were Imperial ($269.70 million) and Tulare ($109.80 million), which combined accounted for 27.9% of state production. Alfalfa was within the top ten agricultural commodities in 23 counties (Alameda, Amador, Colusa, Glenn, Imperial, Inyo, Kings, Lassen, Madera, Modoc, Mono, Merced, Plumas, Riverside, Sacramento, San Bernadino, Shasta, San Joaquin, Shasta, Sierra, Siskiyou, Solano, and Yolo) and within the top four agricultural commodities in ten counties (Amador, Imperial, Inyo, Lassen, Modoc, Mono, Plumas, Riverside, Sierra, and Siskiyou). Figure 3 depicts the geographic distribution of California's alfalfa acreage.

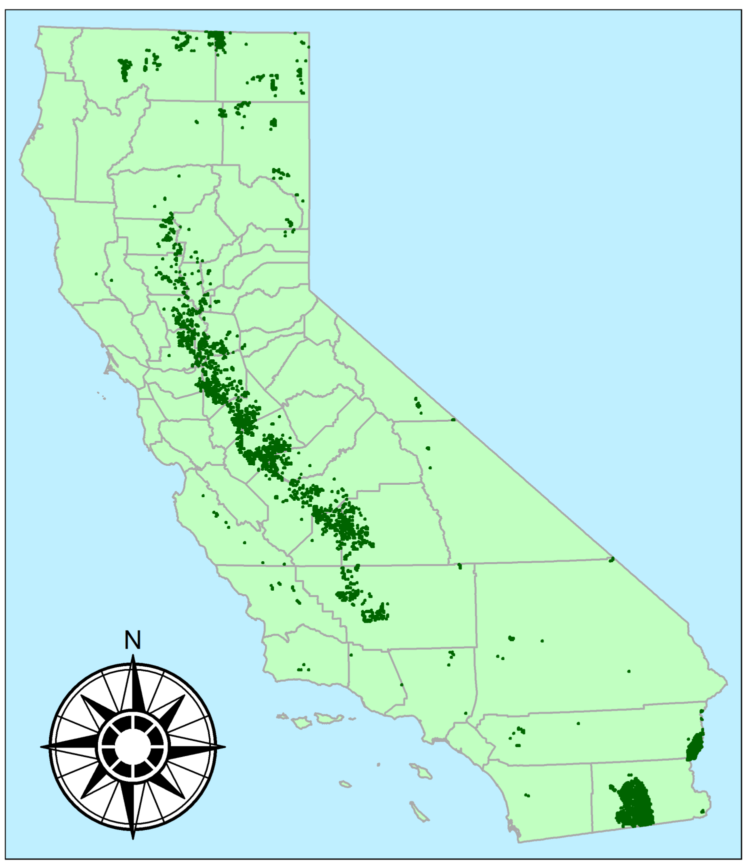


Figure 3: California Alfalfa Production: 2022

IPM Overview

Alfalfa is a perennial crop grown primarily for animal feed in California. A variety of insect pests pose a threat to alfalfa production across California. Alfalfa is harvested in multiple cuttings over the course of the season. Damage to alfalfa by pests therefore is primarily for a given cutting, but pests can also reduce the overall vigor of the plant through their damage, reducing yield in future harvests as well as the stand health across years. Injury to regrowth following cutting can occur. Yield and quality are both very important for alfalfa production, with pests able to affect both. Quality can be affected by chewing pests by changing leaf:stem ratios and piercing-sucking pests by affecting protein content. Alfalfa is grown on a much smaller acreage for seed, with the pest complex and management generally very similar to forage production with some differences. Pyrethroids play a role in the management of a number of pests, with multiple AIs registered and used. Lambda-cyhalothrin is by far the most widely used, but others such as beta-cyfluthrin and zeta-cypermethrin are also used. Pyrethroids are used to manage damaging population levels and severe outbreaks of pests. They also help ensure the long-term efficacy of other insecticide by delaying resistance when used rotationally. Pest managers can employ a number of other tactics to manage some key pests in alfalfa, including resistant varieties, early cutting, modified strip cutting, and conservation of natural enemies.

Target Pests

Weevils

Alfalfa weevil (*Hypera postica*) and Egyptian alfalfa weevil (*Hypera brunnipennis*) are two closely related pests that can cause substantial damage to alfalfa across California. Adults will feed on foliage. All instars of larvae feed on foliage, with young larvae feeding on new buds and older larvae also feeding on leaflets and skeletonizing leaves. There is one generation per year, with minor exceptions, with damaging populations of larvae occurring during the first cutting. Pyrethroids are one of the most commonly used insecticides used for targeting alfalfa weevil, especially lambda-cyhalothrin, followed by zeta-cypermethrin, and beta-cyfluthrin, although permethrin and cyfluthrin can also be used. Indoxacarb is the primary alternative to pyrethroids, and while it is more selective, it also does not have efficacy against aphids, which can co-occur with weevils. In cases where resistance to pyrethroids has occurred at moderate or severe levels, growers have generally switched to indoxacarb. The organophosphate malathion is an alternative, but has poorer efficacy. Spinosad has poorer control and a short residual, which makes managing continued hatches of eggs difficult. This material is therefore most relevant for organic production. Parasitoid wasps have been introduced across the US to provide biological control of weevils, but they generally do not provide good weevil control in California. There is a soil-dwelling fungal pathogen (*Zoophthora phytonomi*) that can reduce populations of weevils in some regions and under certain conditions (sufficient soil moisture). Early harvest is a cultural method that can prevent substantial defoliation, although there may be yield tradeoffs and larvae may survive and be concentrated in windrows, where they can damage re-growing plants. Grazing with livestock during the winter can reduce the number of eggs overwintering in stems. However, this practice is not often done solely for pest management benefits. Given the very limited cultural management tactics, insecticides play a key role in alfalfa weevil management. However, the very limited number of modes of action that are registered and have good efficacy against weevils has meant that there has been a very high selection pressure for insecticide resistance. Pyrethroid resistance has been documented in localized areas across the western United States (Rodbell et al., 2024). While this has meant pyrethroids have already become ineffective in some areas, they will be an important rotational tool even in those areas if resistance levels diminish through time with little to no use of pyrethroids.

Aphids

There are four aphid species that are pests of alfalfa, pea aphid (*Acythosiphon pisum*), blue alfalfa aphid (*Acyrthosiphon kondoi*), cowpea aphid (*Aphis craccivora*), and spotted alfalfa aphid (*Therioaphis maculate*). There are regional and species-specific differences in timing, but they can occur throughout the year in some areas. They damage through direct feeding on phloem or through a combination of direct feeding and injecting toxins while feeding that damages plants. Blue alfalfa aphid and cowpea aphid are the most damaging and prevalent species, and both inject a potent toxin that can stunt or even kill plants. Spotted alfalfa aphid also injects a toxin but is less prevalent. Pea aphid is the least damaging species because it does not inject a toxin while feeding. Aphids can also produce honeydew, which can cover foliage and foster sooty mold growth, which reduces photosynthesis. Alfalfa with honeydew and sooty mold suffers from reduced quality.

Blue alfalfa aphid is often the most damaging aphid species and is a cool-weather aphid whose populations develop during the cooler months. At this time, natural enemy populations have not built up. Cowpea aphid is the other most damaging species and it occurs in most areas during the summer months. Pea aphid populations develop when temperatures are cooler, although they are less tolerant than blue alfalfa aphid to cold temperatures. Aphid management typically starts with the use of resistant varieties. Host plant resistance has been bred into many alfalfa varieties, although resistance differs by variety, and variety choice is affected by more than only pest management (agronomic traits). Resistance is available in alfalfa varieties for all of the four species other than cowpea aphid. The various pyrethroids can all play a role for aphid management, although not typically for blue alfalfa aphid because efficacy of pyrethroids is poor for this species. Other materials used for aphid management include methomyl, organophosphates (dimethoate and malathion), flupyradiufurone, afidopyropen, and flonicamid. Aphid populations can be regulated by natural enemies such as parasitoids (e.g., *Aphidius ervi*, *A. smithi, Lysiphlebus testaceipes*) and predators like lady beetles, big eye bugs, spiders, and lacewings. Use of selective insecticides or border cutting/strip cutting can help retain natural enemies. Broad-spectrum materials, including pyrethroids, can be very disruptive of natural enemies and lead to other pest issues or resurgence of aphid populations.

Grasshoppers

Grasshoppers (*Melanoplus* spp., *Trimerotropis* spp.) are sporadic pests of alfalfa but can be highly damaging during localized outbreaks. Grasshoppers tend to most often be an issue in the Intermountain production region. They frequently will develop in uncultivated areas and then move into fields. They feed on both stems and leaves as immatures and adults and can cause severe defoliation at high populations. Pyrethroids (lambda-cyhalothrin, beta-cyfluthrin, and zeta-cypermethrin in particular) are a primary option for grasshopper management. Chlorantraniliprole is an alternative material, although timing of applications to target immatures is critical to achieve good efficacy.

Leafhoppers and Hoppers

Leafhoppers species (*Empoasca* spp.) and three-cornered alfalfa hopper (*Spissistilus festinus*) are pests of alfalfa, especially in the Low Desert region, but also in the southern Central Valley region. Leafhoppers in the genus *Empoasca* are frequently grouped together as a pest, but there are three species of *Empoasca* leafhoppers that can damage alfalfa, all with the same general appearance and general biology and damage: potato leafhopper (*Empoasca fabae*), garden leafhopper (*Empoasca solana*), and Mexican leafhopper (*Empoasca mexara*). Both adult and nymph *Empoasca* leafhoppers damage alfalfa by extracting plant juices as well as injecting a toxin while feeding, yellowing and stunting plants, sometimes into the next cutting cycle. They can also reduce quality by reducing protein content of harvested alfalfa. Pyrethroids (lambda-cyhalothrin, beta-cyfluthrin, zeta-cypermethrin, permethrin) are frequently relied upon for management. Alternatives include methomyl, dimethoate, and flupyradifurone. Early cutting can manage damaging leafhopper populations.

Three-cornered alfalfa hopper adults and nymphs feed on phloem at the base of the alfalfa plants. Females lay their eggs in stems, and both feeding and oviposition can cause injury by girdling the stem. Pyrethroids (lambda-cyhalothrin, beta-cyfluthrin, zeta-cypermethrin, permethrin) are frequently relied upon for management, with multiple AIs sometimes used in a tank mixture to achieve desirable efficacy. Alternatives include methomyl and flupyradifurone. Weed management in weedy margins can help reduce overwintering populations. Similar to leafhoppers, three-cornered alfalfa hopper damage can sometimes be reduced by early cutting.

Cutworms

Two species of cutworm, granulate cutworm (*Feltia subterranea)* and variegated cutworm (*Peridroma saucia)* cutworms can be sporadic pests across California but are most commonly problematic in the low desert. Populations develop in field margins and weedy areas and move into alfalfa fields. They can damage both established and newly planted fields, with damage especially severe in seedling stands. Pyrethroids (lambda-cyhalothrin, beta-cyfluthrin, zeta-cypermethrin) are used for cutworms. Alternatives include chlorantraniliprole, indoxacarb, methoxyfenozide, or *Bacillus thuringiensis* materials. Cultural controls include managing weeds in border areas, managing weeds within the field, avoiding high plant residue, flood irrigation, and conservation of natural enemies.

Armyworm

Two species of armyworm, beet armyworm (BAW, *Spodoptera exigua*) and western yellow-striped armyworm (*Spodoptera praefica*) can be abundant at times, and populations can reach damaging levels during the summer. Their populations are somewhat cyclical, with large numbers occurring only every several years. Armyworms skeletonize leaves, leaving veins mostly intact and giving leaves a whitish appearance. Larger larvae cause the most damage and can be somewhat harder to manage with insecticides. Insecticides used for armyworm control are typically methoxyfenozide, chlorantraniliprole, indoxacarb, or methomyl. Pyrethroids are not the primary insecticide used, but may sometimes used for armyworms, typically as part of a pre-mix or tank mixture (lambda-cyhalothrin, zeta-cypermethrin, etc.). *Bacillus thuringensis aizawai* insecticides are also used for armyworms (typically in organic production) and are highly compatible with natural enemies. Early harvest and border-strip cutting can help manage armyworms. Biological control by generalist predators and parasitoids in particular can often be significant, eliminating the need for insecticide applications. Viral diseases can also quickly spread through armyworm populations and reduce their numbers.

Alfalfa Caterpillar

The alfalfa caterpillar (*Colias eurytheme*) can occur at damaging levels during the summer or early fall. Damaging/outbreak levels are typically cyclical, occurring every few years. Flights of adults will disperse between fields and create infestations. Damaging populations can result from slow and uneven alfalfa growth, hot dry weather, and lack of natural enemies (possibly due to hyperparasitoids attacking the primary parasitoids). This species damages foliage by consuming leaves, and larger larvae are most destructive. Insecticides used for alfalfa caterpillar control are typically methoxyfenozide, chlorantraniliprole, indoxacarb, or methomyl. Pyrethroids are not the primary insecticide used for alfalfa caterpillar, but may sometimes be used for armyworms (lambda-cyhalothrin, zeta-cypermethrin, etc.), typically as part of a pre-mix or tank mixture with another AI . *Bacillus thuringensis aizawai* insecticides are also used for alfalfa caterpillar (typically in organic production) and are highly compatible with natural enemies. Parasitoids in particular can be effective at controlling alfalfa caterpillar populations. Border-strip harvesting and overall conservation of natural enemies are alternative management strategies.

Webworm

Webworms (*Loxostege* spp.) are infrequent pests of alfalfa. Larvae fold leaves into shelters using webs, providing themselves shelter. They will feed on foliage and can defoliate alfalfa as they feed within their shelters. Management is not typically warranted unless populations are very high. If chemical control is warranted, options include the pyrethroids lambda-cyhalothrin, beta-cyfluthrin, and zeta-cypermethrin.

Pale-striped Flea Beetle

Pale-Striped Flea Beetle (*Systena blanda*) in alfalfa are occasional pests that are most problematic for seedling stands. Adult beetles feed on undersides of leaves and create pits or holes in leaves. Large numbers can kill or stunt seedlings. Pyrethroids (lambda-cyhalothrin, beta-cyfluthrin, and zeta-cypermethrin) are the primary insecticides used against flea beetles. Field sanitation and keeping field margins weed free are cultural control tactics for this pest.

Lygus Bugs

Lygus bug (Lygus spp.) are the primary insect pests in seed alfalfa production, but not an economic pest of forage alfalfa. Adults and nymphs will preferentially feed on plant terminals, buds, flowers and developing seeds. This results in physical damage from probing with their mouthparts and removing plant juices, chemical damage (deformed growth and death of plant tissue), and shedding of flowers and seed pods. Damage can be extreme with high, unmanaged populations of lygus. Adults and large nymphs cause the most damage. Pyrethroids are one of the insecticide groups used to target lygus in seed alfalfa (lambda-cyhalothrin, beta-cyfluthrin, zeta-cypermethrin). Alternative insecticides include flonicamid, dimethoate, and novaluron. Broad-spectrum materials like pyrethroids are applicable for pre-bloom control of lygus, but not during bloom due to toxicity to pollinators, which are managed in alfalfa seed production. Vegetation management can help reduce damage as weeds can serve as sources of lygus. Management of other crops, such as forage alfalfa, can also reduce risk of release of lygus adults (such as by harvesting fields before adult populations are high).

Pyrethroid Use: 2020–2022

In alfalfa, pyrethroid use increases significantly in late winter to early spring for control of weevils and aphids. Pyrethroids are then used continuously throughout the season, in mixes or in rotation with other insecticides, for control of multiple pest species.

Table 1 reports pounds applied, acres treated, and use rates for pyrethroids and alternative AIs in alfalfa. Malathion and dimethoate were applied on the most acres treated. Lambda-cyhalothrin was the pyrethroid applied on the highest number of acres. In contrast, the other pyrethroids (zeta-cypermethrin, beta-cyfluthrin, cyfluthrin, and permethrin) were used relatively less than the majority of alternative AIs in alfalfa.

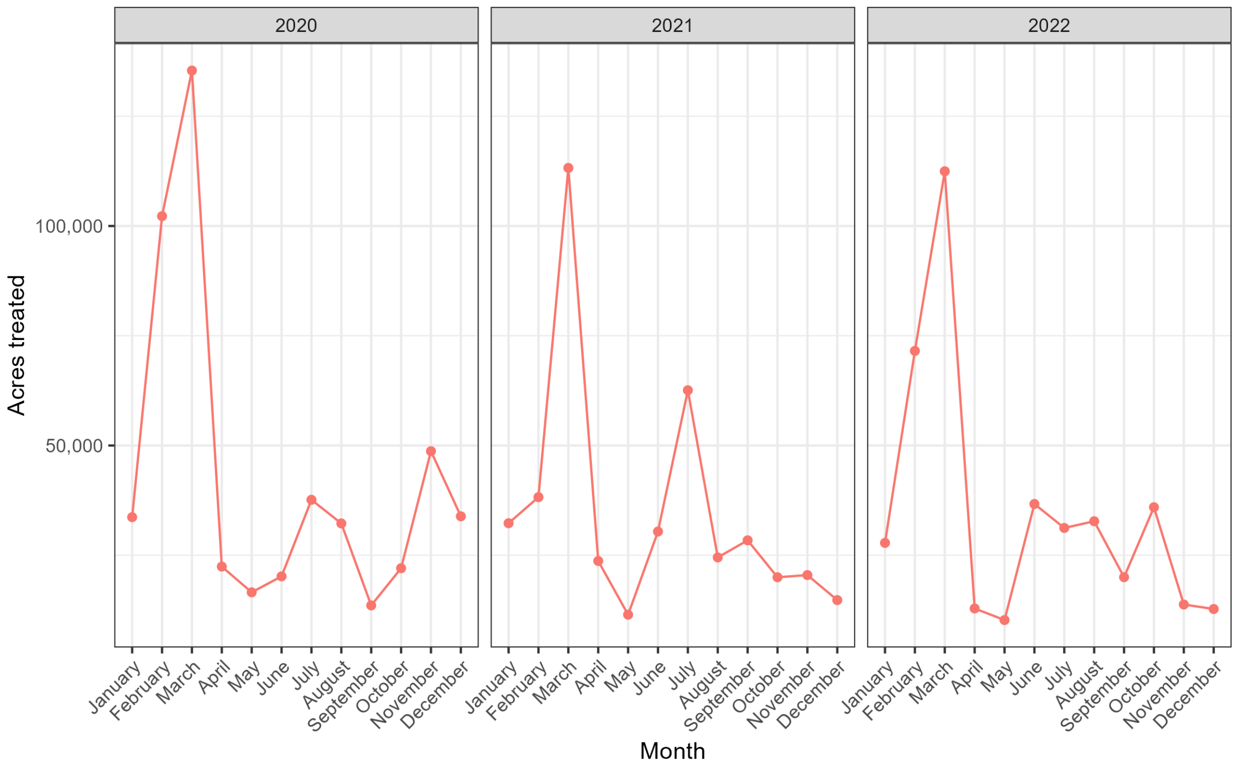


Figure 4: Monthly Use of Pyrethroids: Alfalfa, 2020–2022

Table 1: Annual Use of Pyrethroids and Alternative Active Ingredients: Alfalfa, 2020–2022

	Lbs. Applied				Acres Treated				Use Rate (lb/ac)
Active Ingredient	2020	2021	2022	Total	2020	2021	2022	Total	
afidopyropen	1,025	2,206	NA	3,231	46,758	96,512	NA	143,269	0.02
bacillus thuringiensis	2,500	2,424	4,140	9,064	22,246	5,416	10,776	38,438	0.24
beta-cyfluthrin*	1,439	1,110	1,253	3,802	62,367	48,799	55,964	167,131	0.02
cyfluthrin*	562	637	663	1,862	13,970	15,290	16,229	45,488	0.04
dimethoate	38,885	21,789	69,048	129,722	129,397	78,557	211,121	419,075	0.31
flonicamid	3,651	2,687	3,225	9,563	42,451	30,999	37,255	110,705	0.09
flupyradifurone	14,229	15,704	19,150	49,083	133,878	150,199	171,175	455,252	0.11
indoxacarb	13,838	14,424	17,382	45,644	152,055	142,064	197,594	491,714	0.09
lambda-cyhalothrin*	9,047	9,360	12,308	30,715	306,243	316,427	401,549	1,024,219	0.03
malathion	35,902	38,004	48,860	122,766	34,415	35,486	45,163	115,064	1.07
methomyl	11,408	8,219	13,020	32,648	14,799	10,576	18,351	43,726	0.75
novaluron	51	3	130	184	649	32	1,663	2,344	0.08
permethrin*	4,510	2,433	6,368	13,311	27,280	13,741	38,384	79,405	0.17
spinosad	23	46	75	144	497	861	1,432	2,790	0.05
zeta-cypermethrin*	281	642	305	1,227	10,236	23,679	6,456	40,371	0.03

*Target Pyrethroids

Economic Analysis

This section presents the expected change in net revenues for alfalfa if pyrethroid insecticides became unavailable. This cost includes the change in pesticide material costs on acres previously treated with pyrethroids. We anticipate no change in application costs. In the absence of any anticipated effect on yields, gross revenues will not change. Consequently, the only impact on net returns is the impact on pesticide material costs. The AIs chlorantraniliprole and methoxyfenozide, although briefly mentioned in the Target Pests section, were not included in the analysis as they are not alternatives to pyrethroids for the pests they target and their use would not be expected to increase without pyrethroids.

Table 2 presents representative products for pyrethroids and alternative AIs used on alfalfa from 2020 to 2022 and their material costs per acre. The material cost per acre is the product of the average use rate (lb/ac) over this period and the price per pound. The average use rate was computed by dividing total pounds applied over the three-year period by the total acres treated. Price per pound of AI was calculated based on the product formulation and product price. The cost per acre ranges from $1.05 to $39.37.

Table 2: Representative Product Cost per Acre: Alfalfa, 2020–2022

Active ingredient	**Representative product**	**Cost per acre ($)**
afidopyropen	Sefina Inscalis Insecticide	22.08
bacillus thuringiensis	Dipel Df Biological Insecticide Dry Flowable	9.15
beta-cyfluthrin*	Baythroid Xl	3.49
cyfluthrin*	Tombstone Helios Insecticide	4.14
dimethoate	Dimethoate 400	8.01
flonicamid	Beleaf 50 Sg Insecticide	33.06
flupyradifurone	Sivanto Prime	32.47
indoxacarb	Dupont Steward Ec Insecticide	28.23
lambda-cyhalothrin*	Silencer	1.05
malathion	Gowan Malathion 8	16.96
methomyl	Du Pont Lannate Sp Insecticide	24.89
novaluron	Rimon 0.83 Ec Insecticide	36.84
permethrin*	Permethrin	6.31
spinosad	Entrust Sc	39.37
zeta-cypermethrin*	Mustang Maxx Insecticide	13.72

*Target Pyrethroids

Table 3 provides the acreage shares for the alternatives used on alfalfa from 2020 to 2022. The second column reports the acreage share treated with each alternative AI when pyrethroids are available. Averaged over the three-year period 2020–2022, pyrethroids represented 41.7% of the total applications to alfalfa acres treated with either pyrethroids or an alternative

AI. Prohibited applications of pyrethroids were replaced proportionately with alternatives AIs. The third column reports the share of each alternative in the composite alternative used to replace applications that would be prohibited under the proposed regulation. The most applied alternative AI is indoxacarb, accounting for 26.0% of alfalfa acres treated with pyrethroids or its alternatives.

Table 3: Average Annual Acreage Shares of Alternative Insecticides with and without Pyrethroids: Alfalfa, 2020–2022

Active ingredient	**Pyrethroids available (%)**	**Pyrethroids unavailable (%)**
afidopyropen	6.6	11.3
bacillus thuringiensis	1.2	2.0
dimethoate	12.9	22.1
flonicamid	3.4	5.8
flupyradifurone	14.0	24.0
indoxacarb	15.1	26.0
malathion	3.5	6.1
methomyl	1.3	2.3
novaluron	0.1	0.1
spinosad	0.1	0.1
Total	**58.3**	**100.0**

Note: Three-year average from 2020 to 2022.

Table 4 shows costs per acre for target pyrethroids and the composite alternative. For alfalfa, switching to the composite alternative would increase material costs for all pyrethroids users. The per acre cost would increase by 2,109% for lambda-cyhalothrin users, 566% for beta-cyfluthrin user, 461% for cyfluthrin users, 269% for permethrin users, and 69% for zeta-cypermethrin users.

Table 4: Costs per Acre for Target Pyrethroids and the Composite Alternative: Alfalfa, 2020–2022

Active ingredient	**Cost per acre ($)**	**Cost increase for switching to composite alternative (%)**
beta-cyfluthrin	3.49	566
cyfluthrin	4.14	461
lambda-cyhalothrin	1.05	2,109
permethrin	6.31	269
zeta-cypermethrin	13.72	69
composite alternative	23.24	-

Table 5 summarizes the annual change in total pesticide costs owing to the unavailability of pyrethroids for each of the three base years. The total increase in costs would have been between \$8.73 million and \$11.03 million. In percentage terms costs would have increased between 893.0% and 1,086.6% on acreage treated with pyrethroids. Given that lambda-cyhalothrin is currently the most used and cheapest AI in alfalfa, removing its use will drive a large percentage increase in costs. This story is consistent for the remaining pyrethroids as all are relatively cheap and widely used compared to alternatives.

Table 5: Change in Treatment Costs due to the Unavailability of Pyrethroids: Alfalfa, 2020–2022

Year	**Pyrethroids available (\$)**	**Pyrethroids unavailable (\$)**	**Change in cost (\$)**	**Change in cost (%)**
2020	1,015,503	12,049,971	11,034,467	1,086.6
2021	910,079	9,761,504	8,851,425	972.6
2022	977,951	9,711,305	8,733,354	893.0

Almond

Almond is one of California's most economically important crops. Gross receipts totaled \$5.33 billion in 2022, second only to grapes (\$6.94 billion) in terms of production value (CDFA, 2023a). There were 1.35 million acres of bearing almond orchards in 2022, plus 280,000 non-bearing acres.

Nearly 90 percent of almonds, about \$4.65 billion, are exported, making almond California's most important export agricultural commodity by value. California accounts for all commercial production nationally, and is by far the largest producer and exporter of almonds in the world. For 2023–2024, California almonds were forecast to account for nearly 78% of almonds produced worldwide and more than 85% of almonds exchanged through export markets (USDA Foreign Agricultural Service, 2024).

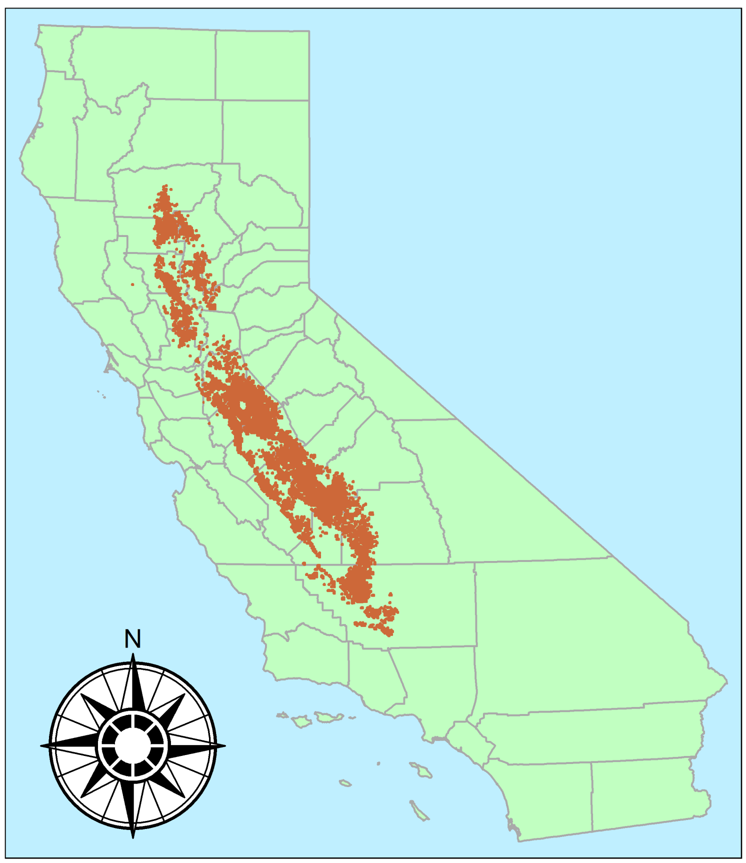
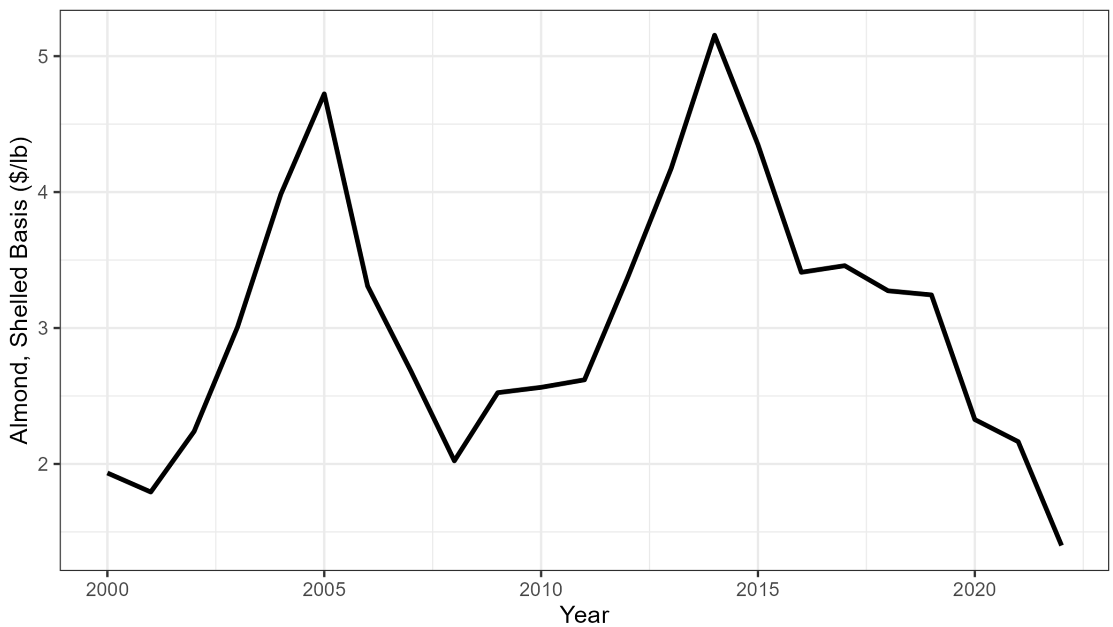


Figure 5: California Almond Production, 2022

Almonds are produced throughout the entirety of the Central Valley, from Redding in the north to Bakersfield in the south, with some additional isolated production closer to the coast near San Luis Obispo. For 2022, almonds were a top four agricultural commodity by value in nine counties (Colusa, Butte, Fresno, Glenn, Kern, Merced, San Joaquin, Stanislaus, and Yolo), the second most important agricultural commodity in five of these counties (Butte, Fresno, Merced, San Joaquin, and Stanislaus), and the top agricultural commodity in four (Colusa, Glenn, Fresno, and Madera). Figure 5 maps the distribution of California's 2022 almond production.

Since 2000, the price per pound of shelled almonds has fluctuated between a low of $1.40/lb in 2022 and a high of $5.05/lb in 2014. Figure 6 graphs the price per pound for shelled almond from 2000–2022. The price peaked in 2004 and 2014, with the latter peak coinciding with the historic 2011–2017 California drought. Supply recovered in 2015 as drought conditions began to recede. Variability in almond prices is also strongly influenced by international demand for California almonds, particularly from Asia (Swegal, 2017).



Note: Prices are in real dollars (2022) using the Producer Price Index (PPI) for commodities (U.S. BLS, 2022).

Figure 6: Almond Price (Shelled Basis): 2000–2022

IPM Overview

Almonds are grown throughout California in a variety of climatic conditions using diverse agronomic practices. The Sacramento Valley and San Joaquin Valley are the two climatic macro-regions for almond. Even within that there are idiosyncrasies, most importantly between the southern and northern San Joaquin Valley. For the purposes of this report, pesticide use will be evaluated statewide, which requires some generalization about key pests and their management.

Pyrethroids are widely used in almond to control several pest species. The most common AIs are: zeta-cypermethrin, beta-cyfluthrin, bifenthrin, cyfluthrin, deltamethrin, esfenvalerate, fenpropathrin, gamma-cyhalothrin, lambda-cyhalothrin, and permethrin. Of those, use is dominated by bifenthrin, lambda-cyhalothrin, and esfenvalerate.

Target Pests

Leaffooted Bugs (LFB)

There are three leaffooted bugs (LFB) that can be found in almonds: *Leptoglossus zonatus*, *L. clypealis*, and *L. occidentalis*. Of these, *L. zonatus* is currently the most dominant and frequently encountered. These LFB overwinter as adults in sheltered areas near almond orchards (i.e., natural habitats, citrus and olives, landscape plantings, residential areas, etc.) and then in the spring (April/May) migrate into orchards in search of food. LFB are not always a consistent pest but in the right weather large populations can rapidly emerge and cause significant damage. The adults can feed on young nuts using their piercing mouthparts, which can cause the forming nuts to abort. Feeding on mature nuts can cause black spots on the kernel or nut drop. Chlorpyrifos has historically been used to control LFB, however, that is no longer an option with recent restrictions on this and other organophosphates. Currently, there are no alternatives available for control of LFB in almonds, and any restrictions on the use of pyrethroids would present a significant challenge to almond growers.

Without alternatives, it is likely that some growers would likely face yield loss. Joyce et al. (2019) showed that on average over two years 27% of nuts suffered kernel necrosis, making them unmarketable. There is variation within varieties and year; kernel necrosis affected between 18 and 51% of nuts exposed to *L. zonatus* feeding in the study. Currently, LFB are fairly widespread in almond, although some sites tend to be attacked more or less frequently, likely due to their proximity to (or distance from) LFB overwintering sites. Since they are the primary target of spring pyrethroid sprays, the acres treated with pyrethroids in the spring are a reasonable estimate for the number of acres affected by a LFB problem each year. In 2020 to 2022 between 293,000 and 354,000 acres of almond were treated with spring pyrethroid sprays, likely for LFB, each year. The acres affected would likely increase because almond and other significant host crops such as pistachio, citrus, and pomegranate, would also be unable to manage these insects.

Stink Bugs

There are several stink bugs that can be found in almonds: the green stink bug (*Acrosternum hilare)*, the red shouldered stink bug (*Thyanta pallidovirens* and *T. custator acerra*), and the Uhler stink bug (*Chlorochroa uhleri*). The green stink bug is the most common and can overwinter within almond orchards. Stink bugs can also develop around almond orchards, often in weedy field margins, and then migrate into the orchards as adults. Like LFB, they feed using piercing mouthparts which can damage the nuts. Stink bug damage appears in May-July. Clothianidin or acetamiprid may be applied against stink bugs, usually in a tank with bifenthrin or lambda-cyhalothrin, although in such cases the pyrethroids are likely doing most of the heavy lifting. Historically, chlorpyrifos was also a good control option for stink bugs but is no longer available since DPR issued the notice to ban in May 2019 and it was subsequently withdrawn by the registrant. Restrictions on use of pyrethroids would present a significant challenge to almond growers for stink bug control.

Navel Orangeworm (NOW)

NOW is the primary pest of the California almond crop. Adult female moths lay eggs on nuts after hull split and the larvae feed on developing nuts, causing direct crop loss, and this can open the door to fungal infections that produce aflatoxin, a contaminate that is toxic to humans and heavily regulated both domestically and in key export markets. NOW larvae overwinter in unharvested remnant nuts that remain in the orchard from the previous season, i.e., "mummy" nuts. Almond varieties that mature later in the season are more susceptible to NOW damage, as populations steadily build over the course of the year. The longer nuts remain on the tree, the higher probability of NOW infestation. Modern navel orangeworm management consists of (1) winter sanitation, (2) monitoring, (3) well-timed insecticide sprays, (4) timely harvest, and more recently, (5) mating disruption.

Sanitation is the foundation of NOW management. During the winter growers are strongly advised to remove or destroy overwintered remnant "mummy" almonds from their orchards. Sanitation typically involves shaking trees or hand poling to remove "stick tight" nuts from the canopy followed by blowing/sweeping mummy nuts into windrows that can then be destroyed via disking or flail mowing. While this management strategy is strongly recommended, not all growers are able to effectively sanitize due to the costs and/or availability of labor and equipment. Even in the absence of these barriers, poor weather and/or orchard conditions (wet soils) can also impede timely access by heavy machinery and/or field crews to carry out sanitation.

Monitoring is important to know when to expect peak NOW activity. Monitoring with egg traps can allow growers to determine a biofix and begin calculating degree days in order to estimate peak NOW flight and, most importantly, egg-laying activity. This can be supplemented with the use of flight traps with pheromone lures to monitor adult male activity. If a spray is warranted, insecticides are typically applied at hull-split (July) and thereafter, when the new crop is susceptible. Some growers also utilize spring sprays (April/May) during the first flight of NOW if populations are particularly high and/or persistent year-to-year. The AIs that are most commonly applied for NOW include pyrethroids (bifenthrin and lambda-cyhalothrin), insect growth regulators (methoxyfenozide), and diamides (chlorantraniliprole). It is important to note that recent studies have documented NOW resistance to bifenthrin (Demkovich et al., 2015).

Timely harvest is simply a logistical effort to minimize the time that ready-to-harvest almonds remain in the orchard, since probability of infestation steadily rises over time as NOW populations build up over the season, especially with the third flight that occurs in August.

Mating disruption using the pheromone (z,z)-11,13-hexadecadienal can also be an effective tool for NOW management, although the costs ($120-170/acre) and area requirements (i.e., works better when used over larger contiguous areas) do not necessarily work for smaller growers or in years when operating budgets are reduced due to low crop prices. There are currently four commercially available products that are all about equally effective when used in combination with the aforementioned cultural and chemical control strategies. More recently a cheaper flowable mating disruption product has been introduced, although research is still underway to determine efficacy and efficient use. Continuing research on mating disruption would benefit NOW control in almond.

In contrast to LFB and stink bugs, almond growers do have a suite of alternative options for NOW control outside of pyrethroids, and, as mentioned, some NOW populations are now known to be resistant to the pyrethroid bifenthrin. However, pyrethroids are still a critical tool for almond growers, especially when dealing with large and persistent NOW populations, and restricting their use in almonds would present a significant challenge to growers. With improved alternative strategies, pyrethroid use could likely be reduced in almonds; alternative strategies include improved machinery for crop sanitation, subsidies to offset the costs of mating disruption, and mechanisms to promote area-wide adoption of this technology among smaller growers. In the interim, pyrethroids remain an important part of the AI rotations used to manage NOW. By integrating pyrethroids with methoxyfenozide and chlorantraniliprole, the likelihood of insecticide resistance developing for any given AI is reduced.

Peach Twig Borer (PTB)

Peach twig borer is a lepidopteran pest of several tree crops that can damage both young trees and, in almonds, maturing nutmeat through direct feeding. Females lay eggs on twigs, fruit and leaves. Larvae damage both growing shoots and nuts. There are four generations per year. PTB larvae overwinter in sheltered tiny cells called 'hibernacula' that they bore under the bark in limb crotches on young wood, or in bark cracks on older wood. Given this overwintering strategy, one of the most effective control strategies for PTB is achieved through winter dormant applications of the pyrethroid esfenvalerate, which is typically combined with oil treatments for San Jose scale, European red mite, and/or brown almond mites. Other recommended products for dormant period sprays include spinosad, spinetoram, diflubenzuron, chlorantraniliprole, and acetamiprid, along with additional pyrethroids such as bifenthrin and lambda-cyhalothrin. In season controls for PTB can include applications of *Bacillus thuringiensis* (*Bt*) at bloom (February) and/or *Bt*, chlorantraniliprole, spinetoram, emamectin benzoate, or acetamiprid in the late spring (May), the latter possibly being combined with a spring spray for NOW in a high pressure situation. Given the range of alternative products available, the impacts of restricted pyrethroid use on control of PTB in almonds remains unclear. Certainly, pyrethroids are a stronger class of AI that likely have greater impact on PTB compared to *Bt*, spinetoram, chlorantraniliprole and others listed above. One important aspect to note is that PTB can be especially detrimental to young trees, and PTB damage to developing trees can have lasting effects. Losing pyrethroids as an option for strong early control could lead to long term damage; more research is needed to determine the impact.

Pyrethroid Use: 2020–2022

Esfenvalerate is almost exclusively applied as a winter dormant spray around January for control of PTB. There is a secondary (but significantly smaller) spike in use of esfenvalerate around July, which is likely for either NOW or PTB control, although use of this AI at that time of year pales in comparison to the more commonly used pyrethroids bifenthrin and lambda-cyhalothrin.

Bifenthrin and lambda-cyhalothrin are applied in April/May and July, with use of both in July about double what is put on in April/May. While these two AIs closely track each other, use of bifenthrin tends to be slightly more common than lambda-cyhalothrin, due to the perception that this product has better residual activity.

Spring applications of bifenthrin and lambda-cyhalothrin primarily target plant bugs, especially LFB. These spring sprays can also be used for control of NOW and/or PTB, but this is much less common, and typically only in orchards with historically high/persistent pressure. As mentioned, PTB is primarily controlled by winter dormant applications of esfenvalerate.

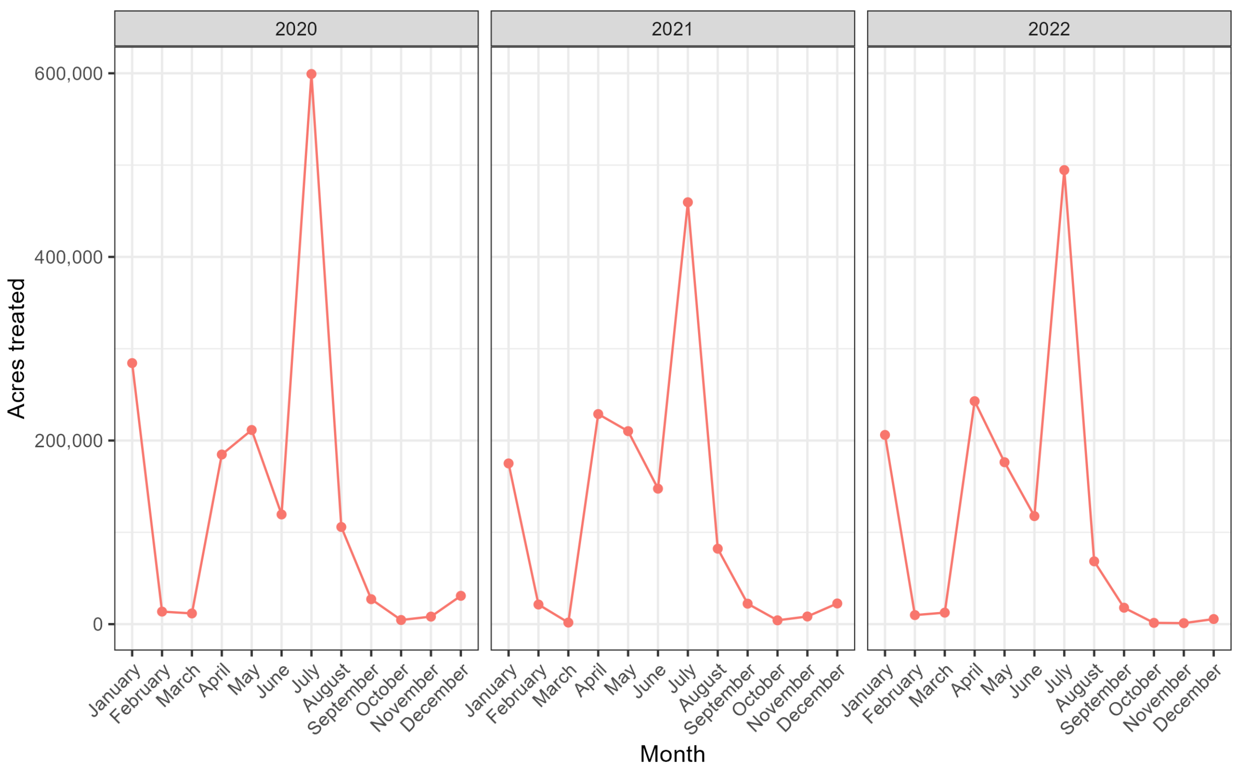


Figure 7: Monthly Use of Pyrethroids: Almond, 2020–2022

Applications of bifenthrin and lambda-cyhalothrin around July are almost exclusively targeting NOW during almond hull-split, when new crop nuts become vulnerable to this pest. A majority of growers utilize a 1–2 spray program for NOW at hull-split, which can include a rotation of one of these pyrethroids with methoxyfenozide and/or chlorantraniliprole. Some NOW control programs only use methoxyfenozide and chlorantraniliprole, with bifenthrin and lambda-cyhalothrin as backup protection in case a third spray is needed or NOW populations are especially high in a given year.

Table 6 reports pounds applied, acres treated, and use rates for pyrethroids and alternative AIs in almond. The pyrethroids bifenthrin, esfenvalerate, and lambda-cyhalothrin were applied in relatively large amounts and over a wide acreage. However their usage generally decreased from 2020 to 2022, which follows the same trend in almond for all other ingredients evaluated. Chlorantraniliprole and methoxyfenozide were the most used alternatives.

Table 6: Annual Use of Pyrethroids and Alternative Active Ingredients: Almond, 2020–2022

	Lbs. Applied				Acres Treated				Use Rate (lb/ac)
Active Ingredient	2020	2021	2022	Total	2020	2021	2022	Total	
(z,z)-11,13-hexadecadienal	686	944	924	2,554	103,480	113,161	93,696	310,337	0.01
acetamiprid	2,640	2,678	2,221	7,539	16,899	19,780	15,219	51,897	0.15
bifenthrin*	110,854	106,872	89,511	307,237	640,972	612,613	508,505	1,762,090	0.17
chlorantraniliprole	89,190	88,638	79,880	257,708	1,037,446	1,030,822	950,296	3,018,564	0.09
diflubenzuron	7,982	4,018	2,090	14,090	32,292	16,480	9,729	58,500	0.24
esfenvalerate*	20,820	14,201	14,644	49,664	297,820	207,539	206,344	711,703	0.07
fenpropathrin*	2,534	2,072	817	5,422	7,024	5,884	2,342	15,250	0.36
lambda-cyhalothrin*	24,097	19,238	21,316	64,652	606,079	498,602	551,439	1,656,120	0.04
methoxyfenozide	282,144	272,798	261,484	816,426	838,933	788,445	754,647	2,382,024	0.34
methoxyfenozide + spinetoram	93,018	77,771	70,646	241,435	484,877	388,369	358,378	1,231,624	0.20
spinetoram	1,712	1,048	1,335	4,095	18,949	11,768	13,597	44,313	0.09
spinosad	1,191	1,290	1,743	4,224	17,089	17,075	22,724	56,888	0.07
zeta-cypermethrin*	106	379	340	825	4,276	13,225	13,666	31,167	0.03

*Target Pyrethroids

Economic Analysis

This section presents the anticipated change in net returns for almond if pyrethroid insecticides became unavailable. Both pest management costs and gross revenues may be affected.

Pest management costs. This cost consists of the change in pesticide material costs on acres previously treated with pyrethroids. We anticipate no change in application costs. Table 7 presents representative products for pyrethroids used on almond in 2020–2022 and their material costs per acre. The material cost per acre is the product of the average use rate (lb/ac) over this period and the price per pound. The cost per acre ranges from $7.34 to $72.34. Growers consider other factors in addition to cost per acre when choosing insecticides, as discussed above.

Table 7: Representative Product Cost per Acre: Almond, 2020–2022

Active ingredient	**Representative product**	**Cost per acre ($)**
(z,z)-11,13-hexadecadienal	Checkmate Now-F	32.66
acetamiprid	Assail 70wp Insecticide	17.95
bifenthrin*	Sniper	13.81
chlorantraniliprole	Altacor Insect Control	42.50
diflubenzuron	Dimilin 2l	33.04
esfenvalerate*	Asana Xl Insecticide	7.34
fenpropathrin*	Danitol 2.4 Ec Spray	29.69
lambda-cyhalothrin*	Besiege Insecticide	11.82
methoxyfenozide	Intrepid 2f	54.00
methoxyfenozide and spinetoram	Intrepid Edge	42.08
spinetoram	Delegate Wg	72.34
spinosad	Entrust Sc	56.79
zeta-cypermethrin*	Mustang Maxx Insecticide	11.94

*Target Pyrethroids

Several adjustments were made to the products included in this analysis. Following the critical use analysis methodology of Steggall et al. (2018), such adjustments are necessary to represent how AIs are applied in practice and their comparative efficacy across products. Almond includes significant use of the product Intrepid Edge, which contains both methoxyfenozide and spinetoram. These AIs target multiple pests (PTB and NOW), and single AI products are also used (Intrepid 2F, methoxyfenozide; Delegate WG, spinetoram). For this reason, Intrepid Edge has been separated into its own category so that acres treated are not reported twice, once for each AI. Additionally, the top used mating disruption pheromone product Checkmate Now-F ((z,z)-11,13-hexadecadienal) has a significantly lower use rate than other (z,z)-11,13-hexadecadienal containing products. To account for this, price calculations have been manually changed to use the almond-average Checkmate Now-F use rate of 0.0021968 lb/acre. Finally, spinosad baits were excluded from the analysis as baits are not used as alternatives to pyrethroid applications in almond production.

Table 8 shows the average acreage shares for each alternative AI with pyrethroids available and if they were unavailable. Averaged over the three-year period 2020–2022, pyrethroids were used on 39.1% of total almond acres treated with pyrethroids or an alternative AI. Total acres treated with one of these insecticides does not correspond to physically unique acres because multiple applications of one or more of these insecticides may be made to an orchard. To evaluate costs if pyrethroids were unavailable, the use of alternative AIs is scaled up in proportion to their acreage shares, as discussed in the methods section. The two most common alternative AIs were chlorantraniliprole and methoxyfenozide, together accounting for 50.5% of total almond acres treated with pyrethroids or its alternatives, which is 83.0% of acres treated with an alternative to pyrethroids.

Table 8: Average Annual Acreage Shares of Alternative Insecticides with and without Pyrethroids: Almond, 2020–2022

Active ingredient	**Pyrethroids available (%)**	**Pyrethroids unavailable (%)**
(z,z)-11,13-hexadecadienal	2.9	4.8
acetamiprid	0.5	0.8
chlorantraniliprole	28.2	46.4
diflubenzuron	0.5	0.9
methoxyfenozide	22.3	36.6
methoxyfenozide and spinetoram	5.8	9.5
spinetoram	0.4	0.7
spinosad	0.3	0.5
Total	**60.9**	**100.0**

Note: Three-year average from 2020–2022.

Table 9 shows the costs per acre for five target pyrethroids and the composite alternative. For almond, switching to the composite alternative would increase material costs. Fenpropathrin users would incur the smallest cost increase (56%) and esfenvalerate users would incur the largest cost increase (529%). The users of lambda-cyhalothrin, zeta-cypermethrin, and bifenthrin would incur a cost increase of 291%, 287%, 235%, respectively.

Table 9: Costs per Acre for Target Pyrethroids and the Composite Alternative: Almond, 2020–2022

Active ingredient	**Cost per acre ($)**	**Cost increase for switching to composite alternative (%)**
bifenthrin	13.81	234.5
esfenvalerate	7.34	529.0
fenpropathrin	29.69	55.6
lambda-cyhalothrin	11.82	290.7
zeta-cypermethrin	11.94	286.7
composite alternative	46.18	-

Table 10 reports the annual change in costs due to the unavailability of pyrethroids for each of the three base years. The total increase in costs would have been between $43.93 million and $53.41 million. In percentage terms costs would have increased between 281.2% and 289.3% on acreage treated with pyrethroids that would have been prohibited. As pyrethroids are widely used in almond production, pest management costs would increase significantly without them. However, the cost per acre of some pyrethroid products like fenpropathrin are close, to costs per acre of alternatives which slightly mitigates the increase in the percentage change in cost relative to other crops like alfalfa.

Table 10: Change in Treatment Costs due to the Unavailability of Pyrethroids: Almond, 2020–2022

Year	Pyrethroids available ($)	Pyrethroids unavailable ($)	Change in cost ($)	Change in cost (%)
2020	18,461,854	71,870,617	53,408,763	289.3
2021	16,209,835	61,788,159	45,578,324	281.2
2022	15,288,271	59,221,845	43,933,574	287.4

Change in gross revenues. Without pyrethroids, no effective management strategies for LFB remain, likely resulting in significant yield losses for almond producers. We projected yield loss associated with LFB by identifying almond acreage treated with pyrethroids in April and May (applications during this period are almost exclusively for LFB) and calculated a 25% yield loss on that acreage.

The change in total revenue depends on how the price of almond changes in response to a change in quantity. The own-price elasticity of demand represents the relationship between the change in quantity and the change in price. If an elasticity is smaller in magnitude than -1 (inelastic), an increase in price is associated with a less than proportionate increase in the quantity demanded, and total revenue increases. If it is larger than -1 in magnitude (elastic), then the decrease in the quantity demanded is larger than proportionate than the change in price and total revenue falls. If the own-price elasticity of demand is -1, then gross revenue remains the same. The largest gross revenue decline occurs when demand is perfectly elastic (elasticity = $-\infty$). In this case there is no increase in price when the quantity produced declines. Perfectly elastic demand corresponds to a case where California production is a small share of total market production and thus has little influence on the market-clearing price. Almonds are produced exclusively in California and were the top valued export commodity in 2022 (CDFA, 2023a). California is a significant producer in the global almond market. Reductions in California's supply would likely increase the market-clearing price. We apply two own-price elasticity estimates for California almond: an imperfect elasticity (-1.06) and perfect (infinite) elasticity. The imperfectly elastic estimate is the average of the own-price elasticities of demand for domestic consumption (-1.05, Bakhtavoryan et al. 2022) and exports (-1.07, Sisman 2016).

If pyrethroids were available, California almond farmers would receive the price and yield reported in the 2022 California Agricultural Statistics (CDFA, 2023a). Table 11 reports the outcomes under the two own-price demand elasticities: the perfectly elastic scenario (no price change, Column 4, Table 11) and the imperfect elastic scenario (Column 5, Table 11), which uses an own-price elasticity of -1.06 resulting in an approximately 7.0% larger price than the perfectly elastic scenario.

Table 11: Annual Yield and Price for California Almond

Yield (tons)		Price ($/ton)		
Pyrethroids available	Pyrethroids unavailable	Pyrethroids available	Pyrethroids unavailable	
			Perfectly elastic Elasticity=-∞	Imperfectly elastic Elasticity=−1.06
0.95	0.84	2,800.00	2,800.00	2,997.23

Gross revenue is the product of output (yield × acreage) and the realized price. Table 12 reports the estimated change in gross revenues for California almond due to pyrethroids being unavailable. Under the expected 25% yield loss for the months of April and May, the magnitude of the change in gross revenue depends on the elasticity of demand. Under the perfectly elastic scenario (Elasticity = -∞), gross revenue losses range from $247.2 million to $275.5 million, or 10.2% to 12.2%. Under the imperfectly elastic scenario, gross revenue losses range from $94.0 million to $135.8 million, or 3.9% to 6.0%.

Table 12: Change in Gross Revenue due to 25% Yield Loss on Acreage Treated with Pyrethroids from the Unavailability of Pyrethroids, 2020–2022

Year	Gross revenue with pyrethroids available ($)	Gross revenue with pyrethroids unavailable ($)	Change in gross revenue ($)	Change in gross revenue (%)
Perfectly elastic: Elasticity = -∞				
2020	2,421,929,548	2,174,749,141	247,180,407	10.2
2021	2,259,016,864	1,983,489,502	275,527,362	12.2
2022	2,168,181,268	1,905,073,979	263,107,290	12.1
Imperfectly elastic: Elasticity = -1.06				
2020	2,421,929,548	2,327,933,651	93,995,897	3.9
2021	2,259,016,864	2,123,202,107	135,814,757	6.0
2022	2,168,181,268	2,039,263,168	128,918,101	5.9

Note: Reported gross revenue reflects harvested acreage treated with pyrethroids during the 2020–2022 period.

Celery

California harvested approximately 735,625 short tons of celery from 27,500 acres in 2022, representing 100% of all celery produced in the US during this period (CDFA, 2023a; USDA National Agricultural Statistics Service, 2024b).

Celery is harvested year-round. Gross receipts for celery total $450.1 million in 2022, ranking as California's 26th largest agricultural commodity by production value (CDFA, 2023a). California celery exports totaled $78 million in 2022, with nearly 90% sent to Canada.

Figure 8 maps 2022 celery production, with the majority occurring along California's coast. The three largest producing counties in California by value were Monterey ($180.50 million), Ventura ($127.40 million) and Santa Barbara ($67.50 million), which combined accounted for 83.4% of state production.

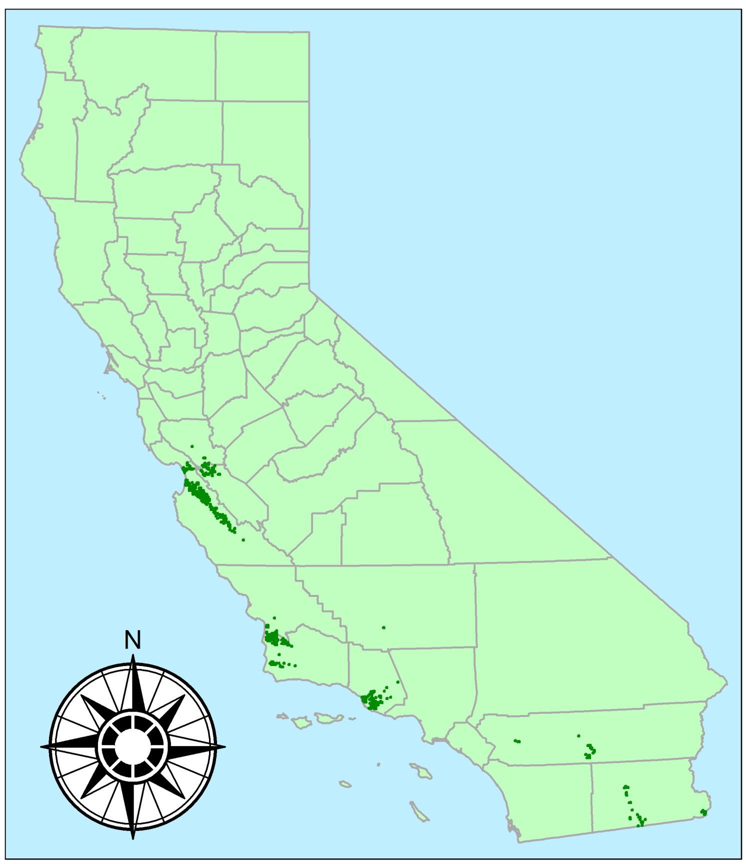


Figure 8: California Celery Production: 2022

IPM Overview

Celery is attacked by a variety of insect pests across most growth stages, feeding on both unharvested and marketable plant parts. While biological control is prevalent in controlling some pest species, broad-spectrum insecticide applications for certain species can periodically reduce natural enemy populations. Pyrethroid insecticides in widespread use include beta-cyfluthrin, bifenthrin, cyfluthrin, zeta-cypermethrin, and permethrin. While alternatives to pyrethroids are available for all significant pests in celery, management programs without them would be expensive and would rely on only a few AIs which could lead to rapid resistance development.

Target Pests

Beet Armyworm (BAW)

BAW is a major pest of celery in California. Young BAW larvae feed on the leaf tissue and are of little economic concern to the growers. However, as the larvae mature, they start feeding on the leaf petiole (harvestable portion of the celery). Feeding on the outer petiole is removed during harvest, and is of little concern to the growers. However, if BAW feeding occurs on the central petioles then the celery is unmarketable (Van Steenwyk and Toscano, 1981). High BAW populations can render an entire field unharvestable as larvae can rapidly move from plant to plant causing serious damage, especially when marketable petioles are forming. Since later instar larvae are much more difficult to control than first and second instar larvae, control is applied as soon larvae are detected on plants. Control of BAW has relied on repeated applications of methomyl and pyrethroid insecticides. Resistance of BAW to methomyl and permethrin has been documented in California. Despite the increase in resistance to both methomyl and permethrin, they are still widely used for control of lepidopteran pests of celery. Control of BAW with repeated applications of reduced risk insecticides like cyantraniliprole, spinetoram, methoxyfenozide, and bacillus thuringiensis has been shown to be as effective as repeated applications of methomyl and permethrin (Kund and Trumble, 2016).

Cutworm (CW)

Black cutworm (*Agrotis ipsilon*), Granulate cutworm (*Feltia subterranean*), and Variegated cutworm (*Peridroma sauci*) are three species of CW that can damage celery plants. After hatching, the young larvae feed on the celery leaves, but cause minor damage to the celery plant. However, as the larvae mature, they drop to the ground and tunnel into the soil. At night, the larvae emerge from the soil and feed on the new transplanted plants. This feeding can kill the young plant or seriously stunt the growth of the plant resulting in uneven stand. As the celery matures, the mature CW larvae feed on the interior petioles of the plant. This feeding makes the plant unmarketable. Control of the mature CW is difficult due to their tunneling in the soil and feeding in the interior of the plant. Thus, control needs to be directed against the young larvae that are exposed to the outer leaves. Control of CW in celery can be achieved by applications of methomyl or a number of pyrethroid insecticides.

Cabbage Looper (CL)

Cabbage looper (*Trichoplusia ni*) get their name by their method of crawling. They arch their backs in a looping manner while holding on with their prolegs. Young CL larvae feed on underside of the leaves of newly transplanted young celery plants where they do minor damage. However as the larvae grow, they can consume enough leaf tissue and stunt the plant growth. This will produce uneven stands of celery, which results in reduced yield. CL are not major pests of celery and can be controlled by a number of parasitoids, including *Trichogramma pretiosum, Hyposoter exiguae, Copidosoma truncatellum,* and *Microplitis brassicae*. These parasitoids along with nuclear polyhedrosis virus usually keep looper populations under control. However, when the parasitoids have been depleted by repeated insecticide applications then chemical control may be necessary. This is particularly true when large larvae are observed on the plants. Non-pyrethroid insecticides available to control CL include methoxyfenozide, spinetoram, spinosad, chlorantraniliprole, and bacillus thuringiensis.

Leafminers (LM)

Vegetable leafminer (*Liriomyza sativae*), serpentine leafminer (*Liriomyza trifolii*) and pea leafminer (*Liromyza langei*) are three species of LM that attack celery. The larvae of all three LM cause similar damage by mining the leaves of the developing celery plant. LM larvae feed between the upper and lower surface of the leaves, making distinctive winding, whitish mines. Under high population pressure, this feeding stunts celery plant growth and reduces celery yield. In addition, the pea leafminer may also mine the marketable celery stalk, making the plant unmarketable. The LM populations are usually held under adequate biological control by parasitoid wasps and a number of predators that feed on LM pupae. However, when these parasitoids/predators are killed by broad-spectrum insecticides such as methomyl, permethrin or other pyrethroid insecticides for control of lepidopteran pests (BAW, CW and CL), then LM populations can explode to damaging levels.

To prevent damaging populations of LM, growers apply abamectin, cyromazine, or oxamyl. Chlorantraniliprole, cyantraniliprole, methoxyfenozide, and spinetoram can also be used with reduced adverse effects on the LM parasitoids/predators.

Aphids

There are four species of aphids that can attack celery: Foxglove aphid (*Aulacorthum solani*), black bean aphid (*Aphis fabae*), cotton/melon aphid (*Aphis gossypii*), and green peach aphid (*Myzus persicae*). Aphids can vector a range of damaging viruses and contaminate fresh market celery with honeydew and disease. Biological control by lady beetles, syrphid flies, lacewings, and parasitoid wasps can reduce high aphid populations within a short period of time. However, control of BAW, CW and LM with pyrethroids often reduces the lady beetle, syrphid flies, lacewing, and parasitoid populations to an ineffective level. While pyrethroids are not recommended for aphid control in celery, this loss of biological control can result in the need for chemical control measures.

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Lygus Bugs

Western tarnish plant bug (*Lygus hesperus*), feed on celery by piercing plant cells which causes sunken, callused, elongated lesions with inner petioles that may show black spots or abnormal deformities. Large numbers of adult lygus can move into celery fields in the spring when weedy vegetation dries. Lygus can do significant damage to the celery crop particularly to young plants in a short period of time. Control of lygus relies on methomyl, acephate, flupyradifurone, flonicamid, oxamyl, sulfoxaflor, and permethrin or other pyrethroid insecticides.

Pyrethroid Use: 2020–2022

Pyrethroid insecticides represented 15.5% of all insecticides applied to celery from 2020–2022, with peak use occurring from August through October after pest populations have built up (CDPR, 2023). The most widely used pyrethroid was permethrin, which was the AI used in 78% of all pyrethroid applications by acreage treated.

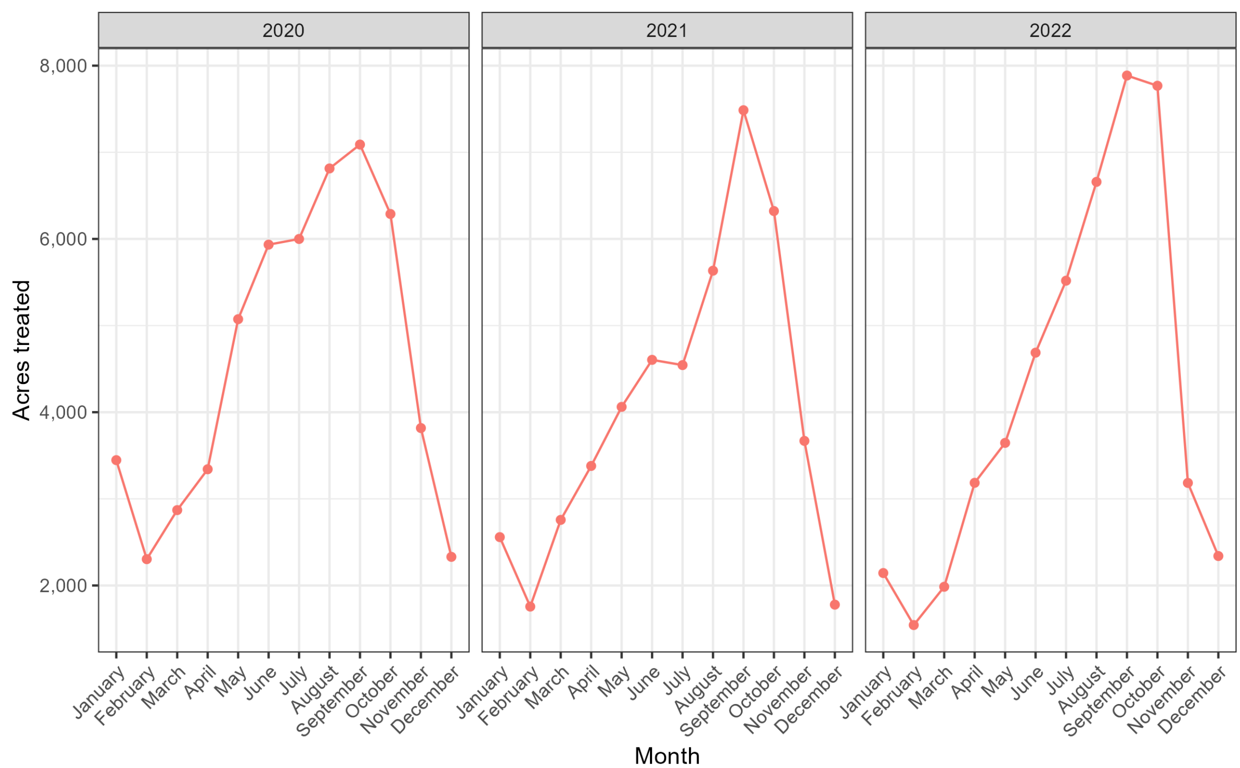


Figure 9: Monthly Use of Pyrethroids: Celery, 2020–2022

Table 13 reports pounds applied, acres treated, and use rates for pyrethroids and alternative AIs in celery. Abamectin and chlorantraniliprole were the most widely used in terms of acres treated. Bifenthrin was used the most out of the pyrethroids but remained a relatively-small share of overall use. The other pyrethroids, beta-cyfluthrin and cyfluthrin, were used relatively less than the majority of alternative AIs in celery.

Table 13: Annual Use of Pyrethroids and Alternative Active Ingredients: Celery, 2020–2022

Active ingredient	Pounds applied				Acres treated				Use rate (lb/ac)
	2020	2021	2022	Total	2020	2021	2022	Total	
abamectin	495	343	334	1,172	30,385	22,212	21,237	73,834	0.02
acephate	11,825	12,263	9,880	33,968	12,348	12,694	10,200	35,242	0.96
bacillus thuringiensis,	7,382	10,473	10,570	28,425	8,527	11,992	12,286	32,805	0.87
beta-cyfluthrin*	70	74	49	193	2,682	2,881	1,870	7,433	0.03
bifenthrin*	582	650	677	1,909	5,955	6,655	6,977	19,587	0.1
chlorantraniliprole	2,351	2,162	2,164	6,677	25,413	23,460	22,144	71,017	0.09
cyantraniliprole	857	678	784	2,319	8,712	7,540	8,752	25,004	0.09
cyfluthrin*	18	28	31	77	368	556	609	1,533	0.05
cyromazine	1,201	1,209	1,233	3,643	9,648	9,702	9899	29249	0.12
flonicamid	782	664	739	2,185	9,114	7,680	8,613	25,407	0.09
flupyradifurone	947	934	731	2,612	6,081	5,822	4,622	16,525	0.16
methomyl	14,840	10,000	11,370	36,210	18,007	12,829	14,316	45,152	0.8
methoxyfenozide	2,107	1,934	1,952	5,993	14,165	13,059	12,908	40,132	0.15
oxamyl	6,829	3,439	2,810	13,078	9,112	4,741	4,265	18,118	0.72
permethrin*	7,289	6,282	6,425	19,996	43,881	37,562	38,521	119,964	0.17
spinetoram	1,533	1,258	1,136	3,927	27,208	22,739	19,778	69,725	0.06
sulfoxaflor	770	876	948	2,594	17,197	18,061	18,460	5,3718	0.05
zeta-cypermethrin*	112	25	71	208	2,422	892	2,568	5,882	0.04

*Target Pyrethroids

Economic Analysis

This section presents the expected change in costs to celery if pyrethroid insecticides became unavailable. This cost only includes the change in pesticide material costs. In the absence of any anticipated effect on yields, gross revenues will not change. The estimates are based on a single application of an alternative replacing an application of pyrethroid.

Table 14 presents representative products for pyrethroids used on celery in 2020–2022 and their material costs per acre. The material cost per acre is the product of the average use rate (lb/ac) over this period and the price per pound. The cost per acre ranges from $3.98 to $72.17.

Table 14: Representative Product Cost per Acre: Celery, 2020–2022

Active ingredient	Representative product	Cost per acre ($)
abamectin	Agri-Mek Sc Miticide/Insecticide	10.49
acephate	Acephate 97up Insecticide	14.85
bacillus thuringiensis	Xentari Biological Insecticide Dry Flowable	34.88
beta-cyfluthrin*	Baythroid Xl	3.98
bifenthrin*	Sniper	7.72
chlorantraniliprole	Dupont Coragen Insect Control	67.17
cyantraniliprole	Minecto Pro	41.67
cyfluthrin*	Tombstone Helios Insecticide	5.05
cyromazine	Trigard	20.76
flonicamid	Beleaf 50 Sg Insecticide	32.92
flupyradifurone	Sivanto Prime	47.60
methomyl	Du Pont Lannate Sp Insecticide	26.73
methoxyfenozide	Intrepid 2f	23.53
oxamyl	Du Pont Vydate L Insecticide/Nematicide	53.03
permethrin*	Perm-Up 25 Df Insecticide	9.00
spinetoram	Radiant Sc	72.17
sulfoxaflor	Sequoia Ca	37.78
zeta-cypermethrin*	Mustang Insecticide	4.53

*Target Pyrethroids

Several adjustments were made to the products included in this analysis. Following the critical use analysis methodology of Steggall et al. (2018), such adjustments are necessary to represent how AIs are applied in practice and their comparative efficacy across products. Celery includes relatively high use of Minecto Pro, a product containing both abamectin and cyantraniliprole. Approximately 75% of abamectin use occurs mostly through other non-multi-AI products, while approximately 75% of all cyantraniliprole use occurs through Minecto Pro. Additionally, the price of Minecto Pro ($3.6/oz) is close to the price of the second most used cyantraniliprole product Exirel ($3.51/oz). For this reason, we have retained Minecto Pro as the representative product for cyantraniliprole and assume the increase in acres treated with abamectin will be proportional to increases in abamectin-only product use (Agri-mek SC Insecticide). Additionally, while the registration of the sulfoxaflor containing product Sequoia expired in 2024, it was available throughout 2020 to 2022 and is thus included in the analysis.

Table 15 shows the average acreage shares for each alternative AI used on celery, with and without pyrethroids being available. Averaged over the three-year period 2020–2022, pyrethroids represented 21.8% of the total applications to celery acres treated with either pyrethroids or an alternative AI. Total acres treated with insecticides do not correspond to physically unique acres because some growers may have used multiple AIs on the same field. To represent the use of alternative AIs if pyrethroids were unavailable, their use is scaled up in proportion to their acreage shares, as discussed in the methods section. The three most common alternative AIs were abamectin, chlorantraniliprole, and spinetoram, together accounting for 30.2% of total celery acres treated with pyrethroid insecticides or the alternatives, which is projected to increase to 38.7% of acres treated without pyrethroids available.

Table 15: Average Annual Acreage Shares of Alternative Insecticides with and without Pyrethroids: Celery, 2020–2022

Active ingredient	**Pyrethroids available (%)**	**Pyrethroids unavailable (%)**
abamectin	10.4	13.3
acephate	5.0	6.4
bacillus thuringiensis	7.2	9.2
chlorantraniliprole	10.0	12.8
cyantraniliprole	3.5	4.5
cyromazine	4.1	5.3
flonicamid	3.6	4.6
flupyradifurone	2.3	3.0
methomyl	6.4	8.2
methoxyfenozide	5.7	7.2
oxamyl	2.6	3.3
spinetoram	9.8	12.6
sulfoxaflor	7.6	9.7
Total	**78.2**	**100.0**

Note: Three-year average from 2020–2022.

Table 16: Costs per Acre for Target Pyrethroids and the Composite Alternative: Celery, 2020–2022

Active ingredient	**Cost per acre ($)**	**Cost increase for switching to composite alternative (%)**
beta-cyfluthrin	3.98	865
bifenthrin	7.72	398
cyfluthrin	5.05	661
permethrin	9.00	327
zeta-cypermethrin	4.53	747
composite alternative	38.43	-

Table 16 shows the average per acre costs for target pyrethroids as well as the cost of the composite alternative, whose price we use as a representative pesticide cost if pyrethroids were unavailable. For celery, switching to the alternative would increase material costs. Beta-cyfluthrin users will incur a per acre cost increase of $34.43, or 865%, zeta-cypermethrin users will incur a per acre cost increase of $33.86 (747%), cyfluthrin users will incur a per acre cost increase of $33.37 (661%), bifenthrin users will incur a per acre cost increase of $30.71 (398%), and permethrin users will incur a per acre cost increase of $29.42 (327%).

Table 17 reports the expected change in costs due to the unavailability of pyrethroids. Insecticide costs for management of the target pests in celery are estimated to increase by more than triple the original costs. The percent increase in costs ranges from 357.5% in 2021 to 359.4% in 2022. Correspondingly, the total change in costs ranges from $1.46 million in 2021 to $1.52 million in 2022. Though pyrethroids are not widely used in celery production, they are considerably cheaper per acre than all alternative AIs with the composite alternative being over four times the price of the most expensive pyrethroid. Without pyrethroids, the higher price of alternative AIs will drive a large percentage increase in the costs of pest control in celery.

Table 17: Change in Treatment Costs due to the Unavailability of Pyrethroids: Celery, 2020–2022

Year	**Pyrethroids available ($)**	**Pyrethroids unavailable ($)**	**Change in cost ($)**	**Change in cost (%)**
2020	464,459	2,125,266	1,660,808	357.6
2021	407,784	1,865,409	1,457,624	357.5
2022	422,743	1,942,212	1,519,469	359.4

Citrus

Citrus includes orange, tangerine (including mandarin), lemon, lime, grapefruit, and other assorted citrus varieties. California accounts for approximately 62% of total U.S. citrus production and 78% of the total value of the U.S. citrus crop. In 2022 there were approximately 270,000 acres of citrus harvested. Total production value for 2022 was $3.2 billion. Orange was the state's 14th largest agricultural commodity by production value, while tangerine and lemon were 18th and 20th, respectively (CDFA, 2023a).

Citrus is grown in four regions across the state of California. Environmental conditions, such as temperature, humidity, and rainfall, differ between regions influencing the type and distribution of pests of concern within IPM programs. For example, lemon is grown primarily on the coast because the mild winter allows for multiple crops to be set on the lemon trees. Each region varies in the profile of citrus-type grown with all regions growing most cultivars. The coastal and desert regions primarily grow lemon, while orange and mandarin are the main varieties in the San Joaquin Valley (SJV). In southern California, lemon, orange, and grapefruit are the dominant types of citrus grown.

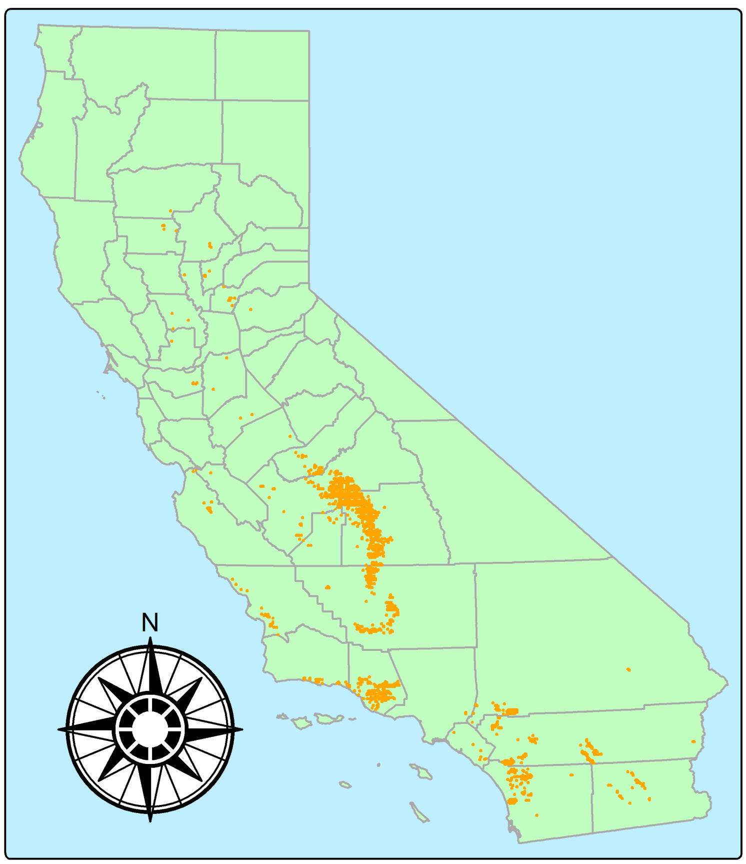


Figure 10: California Citrus Production: 2022

IPM Overview

The climatic differences drive variation in pests and management regimes across regions. The coastal (Ventura, Monterey, Santa Barbara, San Luis Obispo counties) and southern regions (Riverside, San Diego counties) are a much more hospitable climate for biological control agents and as such, growers and PCAs frequently make decisions to preserve the populations by choosing softer insecticides or choosing not to use insecticides at all. In contrast, the extreme summer and winter temperatures in the SJV and the desert regions do not as easily support populations of biological control agents, creating a critical need for insecticides for pest management.

To add to management complexity, the arrival of the Asian citrus psyllid (ACP) in 2008 has disrupted integrated management practices throughout the state (Grafton-Cardwell, 2020). ACP vectors a lethal, bacterial disease of citrus called Huanglongbing (HLB) which is the most destructive disease of citrus worldwide. ACP has established throughout coastal and southern California but has not yet been fully established in SJV, which is the region with 75% of the citrus acreage. In order to keep ACP under eradication in the SJV, growers engage in coordinated insecticide treatment efforts when there are ACP finds and to prevent establishment of the pest. This ongoing program has successfully resulted in eradicating ACP populations when found. The establishment of ACP throughout southern California and coastal region creates a further divide in management practices across the state. In the coastal and southern California regions, where growers treated infrequently and relied on maintaining biological control before the arrival of ACP, they must now treat with insecticides 2-3 times per year to keep ACP populations low in order to slow the spread of HLB. Studies of ACP movement in California showed that ACP can spread via the movement of bulk citrus transported in open trailers to packinghouses (McRoberts and Grafton-Cardwell, 2018).

Several regulations were put in place to minimize the spread, including the tarping of the bulk citrus and the creation of "Bulk Citrus Quarantine Zones" which required mitigations to be applied if fruit is being moved between these zones. These mitigations included spray and move using a preharvest foliar insecticide within 14 days prior to harvest. Products used for this purpose must be of high efficacy and at least a 14-day residual activity, i.e., broad-spectrum insecticides such as pyrethroids and neonicotinoids. Pyrethroids registered for use in California citrus include beta cyfluthrin, bifenthrin, cyfluthrin, fenpropathrin, and zeta cypermethrin.

With the variation in pest issues and citrus varieties by region, the treatment of citrus acreage with pyrethroids by crop type varies by citrus type. California citrus growers have traditionally minimized the use of pyrethroids out of concern for secondary outbreaks of mites and scales, knowing that pyrethroids are highly toxic to natural enemies needed for these pests.

Target Pests

Asian Citrus Psyllid

ACP (*Diaphorina citri*) vectors HLB; there is no known cure for HLB, thus current prevention and management depends on insecticide treatments to limit plant exposure to the vector. With the looming threat of HLB, ACP is managed in an area-wide manner in the coastal, desert, and southern California regions. This means the treatments for ACP are coordinated in order to best suppress populations across an entire area within a 2-3 week period when ACP is most active and conditions are favorable for ACP. ACP nymph population pressure is dependent on leaf flush, also known as new growth. While ACP adults can feed on all leaves and shoots to survive, nymphs can only survive on young flush. Insecticide applications are timed with the flushing periods to prevent egg laying and nymph development and in the winter when the adult population is at its weakest. However, treatment timing is complex due to regional differences and citrus types. In the coastal region, the dominant type of citrus is lemon. Lemon has flush and flowers present throughout the year, requiring frequent treatments to manage of ACP. Orange and mandarin, in contrast, have major flushes in the spring and fall. In California, ACP populations that are reduced with insecticides or by cold conditions in the winter, tend to have very low populations during the spring flush and build during the late summer and fall. Thus, treatments in these crops are timed for fall flush (1–2 treatments) and overwintering adults (1 treatment). In the San Joaquin Valley, ACP is under eradication and pyrethroids and neonicotinoids have been extremely successful in locally eradicating the pest because of their efficacy and long residual life.

Another aspect of citrus production that currently requires pesticide treatment for ACP is shipping fruit. Pyrethroids are key insecticides used for disinfesting fruit of ACP just prior to harvest and shipment in order to prevent the spread of ACP. Pyrethroids are the most effective insecticide in cold weather which is widely recognized across disciplines and winter 'dormant' treatments are a well-known critical tool in vector management (Qureshi and Stansly, 2010).

For ACP management in southern California, pyrethroids are recommended for winter use due to their efficacy at low temperatures. They are also on the list for eradicating psyllids in the San Joaquin Valley and for disinfesting citrus just prior to harvest in order to move bulk citrus between major regions of the state. While there are many alternatives to pyrethroids for managing psyllids, most are contact insecticides with little residual life, thus they are not effective for eradication or disinfestation prior to shipping fruit. In addition, most are not effective in cold temperatures. Some are only effective against nymphs. Thiamethoxam and fenpyroximate are exceptions to these statements, however, thiamethoxam is needed in the fall months to control ACP and other pests that occur at that time. Loss of pyrethroids would increase the frequency of pesticide use for managing and eradicating ACP and shorten the list of available tools for treating and shipping bulk citrus.

Forktailed Bush Katydid

The forktailed katydid (*Scuddaria furcate*) causes serious economic damage to the rind of citrus fruits. As nymphs, they feed on leaves during the bloom period and during fruit set. They prefer fruit and will take single bites from young fruit. The movement of katydids across a field can cause extensive damage quickly throughout a field. While parasitic wasps may attack their egg stage, they do not regulate katydids below the economic threshold. A pyrethroid alternative for katydid control is diflubenzuron, however it is slow acting and does not control populations rapidly enough at petal fall to stop damage. Organophosphates are available, but they have very short residual activity. Growers utilize extremely low rates of pyrethroids to kill the very sensitive katydids and maintain natural enemies for other pests. Thus, pyrethroids can be used as in integrated pest management tactic. With the loss of chlorpyrifos and cryolite for katydid control, only pyrethroids are currently known to exert rapid control of katydids and as a consequence, pyrethroid use for this purpose has increased. Loss of pyrethroids would increase the number of treatments needed for katydid and increase rind damage, resulting in grower losses because severely damaged fruit is culled at the packinghouse.

European Earwig

Earwigs (*Forficula auricularia*) are primarily a concern in new citrus plantings but can also damage new fruit in the spring. In new plantings growers utilize a cardboard wrap around the base of the trunk of the tree for frost and protection from vertebrate pests like rabbits, squirrels, and gophers. Earwigs establish in the wraps and move into the tree, feeding on the new leaves. When left untreated, earwigs densities can reach high numbers and defoliate trees, resulting in poor growth of the trees and a reduction in yield when the trees begin bearing. With the loss of chlorpyrifos spray, growers are currently dependent on pyrethroids for control of earwigs in wraps. In bearing citrus, earwigs feed on the small, developing fruit in the first month after petal fall. The feeding on the rind of young fruit causes large, depressed scarring which causes abscission of the fruit or downgrades the fruit at the packinghouse. Earwigs are difficult to control with insecticides and only broad-spectrum pyrethroids and carbamates are efficacious against this pest if applied to foliage. Carbaryl has a short residual life and multiple applications would be necessary to protect developing fruit. Loss of pyrethroids would increase the number of treatments needed for earwigs and increase young tree damage, resulting in poor health of trees and lower yield when they begin bearing. Loss of pyrethroids in mature trees would result in increased treatments and/or grower losses because severely damaged fruit is culled at the packinghouse.

Southern Fire Ants

Southern fire ant (*Solenopsis xyloni*) is a significant concern in new citrus plantings. In new plantings, growers utilize a cardboard wrap around the base of the trunk of the tree for frost and vertebrate protection. Ants establish in the soil at the base of the wraps and move into the tree, feeding on the new leaves. Left untreated southern fire ant densities can reach high numbers and defoliate trees, resulting in poor growth of the trees and a reduction in yield when the trees begin bearing. Red ants can be controlled by granular insecticides (abamectin, pyriproxyfen, metaflumizone, and chlorpyrifos) applied to the soil. However, labels state they must be spread uniformly on the orchard floor, so they do not protect the area inside the wraps of the trees where the damaging ants reside. Currently, growers are using pyrethroid sprays to achieve effective control of ants inside tree wraps. Loss of pyrethroids would increase tree damage, resulting in poor health of young trees and lower yield when they begin bearing.

Leaffooted Bugs (LFB)

LFB occur in in SJV groves adjacent to pistachio and pomegranate and typically cause damage to mature fruit in the winter and early spring by feeding on mature fruit. Leaf-footed bugs are not a common problem in citrus, but overwintering populations can reside in citrus orchards and feed on citrus; they are very difficult to control with insecticides. Pyrethroids are the only chemicals that are efficacious against leaf-footed bug in citrus. Without pyrethroids, citrus acres could potentially suffer crop loss due to uncontrolled LFB populations. This is compounded by the fact that almond, pistachio, and pomegranate orchards would also be unable to manage LFB.

Fuller Rose Beetle

The fuller rose beetle (*Naupactus godmani*) is a significant concern for citrus growers exporting fruit to South Korea and other Asian markets. This beetle has one generation per year. Adults emerge from the soil year-round; peak emergence in the San Joaquin Valley is from July to September. Although adults feed on citrus leaves, they do not cause significant economic damage. They lay eggs under tight surfaces, including the calyx of fruit, which presents a phytosanitary challenge if viable eggs are intercepted. As eggs hatch, the larvae drop to the ground and spend $\tilde{9}$ months in the soil. As postharvest control of beetle eggs has proven very difficult, growers manage beetle populations in the field by spraying bifenthrin just prior to beetle emergence by June 15 or making two foliar applications of neonicotinoids between August to October 31. Since the phaseout of cryolite, bifenthrin and thiamethoxam applications are the only two choices growers have currently to remain within the regulatory requirements of shipping fruit to Korea. Loss of bifenthrin would increase the likelihood of losing market access.

Glassy-winged Sharpshooter (GWSS)

The glassy-winged sharpshooter, *Homalodisca vitripennis*, is a large leafhopper first found in Southern California in the late 1980s. It feeds on xylem sap of citrus, grapes, and many ornamental plants. Although direct feeding damage isn't a big concern in citrus, high populations reduce fruit quality and yield in citrus. Moreover, GWSS is a key concern in grapes due to its role as a vector of *Xylella fastidiosa*, the bacterium responsible for Pierce's disease. Because citrus orchards can serve as overwintering and breeding sites, they are an important source of GWSS for neighboring vineyards. California growers manage GWSS populations primarily to reduce the risk of spreading *Xylella*. Two types of insecticide applications are used in citrus: suppression sprays during the growing season to reduce GWSS populations, and disinfestation sprays just before harvest to meet quarantine requirements for shipping fruit from infested areas. Although biological control agents, such as egg parasitoids (*Cosmocomoidea* spp.), are established in California and help suppress GWSS numbers, they are often not sufficient for commercial control. Pyrethroids remain an essential tool, particularly for disinfestation before harvest. They provide fast knockdown of mobile GWSS stages and ensure compliance with quarantine regulations. Other AIs recommended for GWSS include imidacloprid, thiamethoxam, flupyradifurone, and cyantraniliprole. The latter two products are used by growers for suppressing citrus thrips in spring. Loss of pyrethroids in mature trees would result in increased treatments or losses to both citrus and grape industries.

Pyrethroid Use: 2020–2022

There are two seasonal trends in pyrethroid use in citrus (Figure 11). Note that each region is scaled differently; the San Joaquin Valley includes an annual average of 274,208 acres of citrus while ACP regions include an annual average of 71,370 acres.

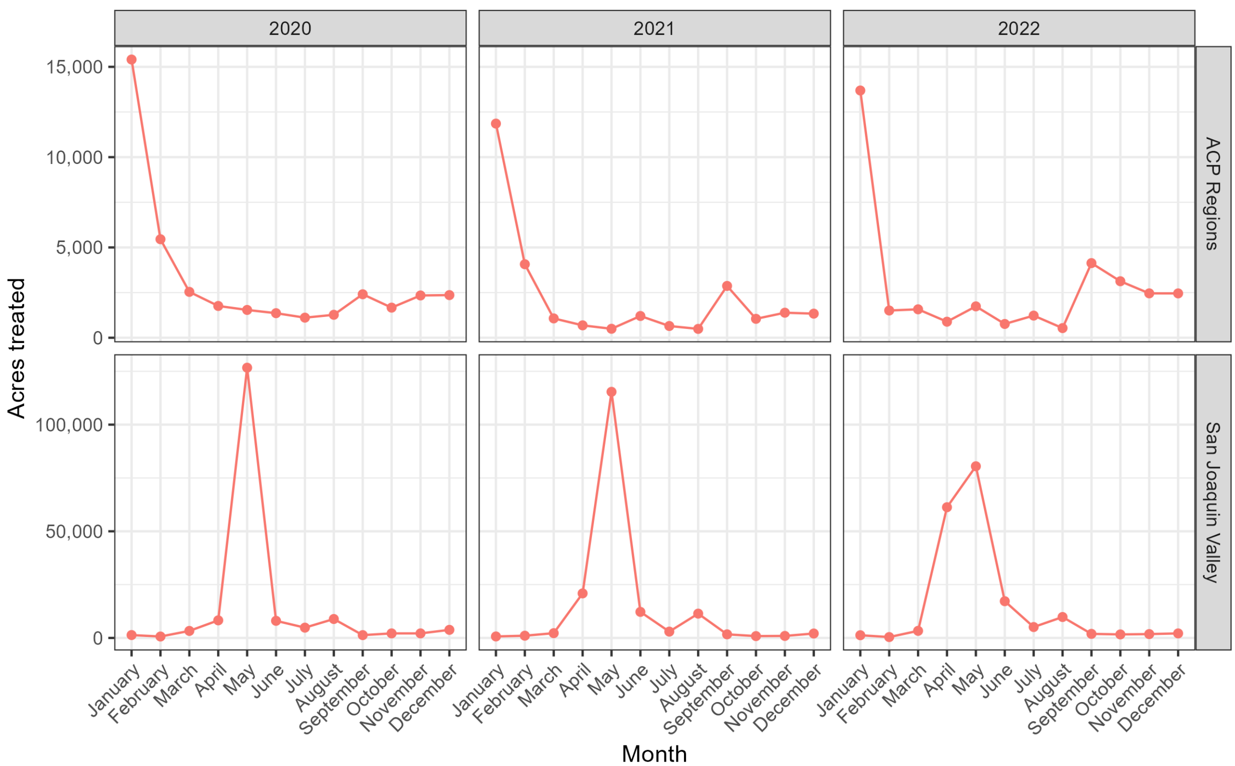


Figure 11: Monthly Use of Pyrethroids by Region: Citrus, 2020–2022

The first trend of treatment occurs in December through March in southern California, the coastal area and desert and is specifically for area-wide and preharvest ACP treatments (Figure 11). The pyrethroid treatments are utilized to knock down adult populations of ACP when their populations are reduced by cold weather and the nymph populations are nonexistent. Pyrethroids are specifically used for this purpose because they are one of the only insecticide modes of action that are effective in cold weather. In addition, growers are required to treat citrus within 14 days prior to harvest to disinfest it of ACP if they move the citrus between bulk citrus quarantine zones. The timing of this disinfestation is harvest in the winter (November-March), and again pyrethroids are the best treatment for that time of year.

The second seasonal trend is the use of pyrethroids on SJV acreage from March through June as a measure to protect early-stage developing fruit from pests during this time. Citrus thrips, earwigs, and katydids simultaneously attack new fruit during this time period. A single pyrethroid eliminates the need for multiple sprays by pest type. There are multiple options for selective and pyrethroid-alternative insecticides for citrus thrips but no other fast-acting option for katydids and earwigs. To reduce the number of sprays, growers choose to combine a selective insecticide for citrus thrips with a broad-spectrum pyrethroid immediately after petal fall (post-bloom) to manage the complex of pests. In addition, when ACP appear in the SJV, pyrethroids are a critical tool to locally eradicate them because of the high level of efficacy.

Table 18: Annual Use of Pyrethroids and Alternative Active Ingredients: Citrus, 2020–2022

	Lbs. Applied				Acres Treated				Use Rate (lb/ac)
Active Ingredient	2020	2021	2022	Total	2020	2021	2022	Total	
abamectin	5,122	6,860	6,334	18,316	236,313	249,795	260,205	746,313	0.02
afidopyropen	17	569	459	1,045	382	12,153	10,618	23,153	0.05
beta-cyfluthrin*	3,384	3,158	2,920	9,462	90,995	83,064	79,253	253,311	0.04
bifenthrin*	4,609	5,860	5,949	16,417	16,511	19,895	18,688	55,094	0.30
carbaryl	18,964	11,525	3,813	34,301	3,553	1,937	926	6,416	5.35
cyantraniliprole	11,217	20,032	17,020	48,269	105,851	127,071	147,236	380,158	0.13
cyfluthrin*	2,957	2,826	3,736	9,518	39,836	38,883	50,392	129,110	0.07
diflubenzuron	16,752	17,659	16,943	51,354	82,709	79,639	78,311	240,659	0.21
dimethoate	4,204	3,365	4,633	12,202	7,240	7,176	7,064	21,480	0.57
fenpropathrin*	19,995	17,327	18,841	56,163	57,298	49,322	51,019	157,640	0.36
flupyradifurone	4,936	4,269	7,068	16,274	33,747	29,329	45,295	108,371	0.15
imidacloprid	52,729	46,915	57,042	156,687	114,875	103,826	67,741	286,441	0.55
pyrethrins	1,006	1,180	967	3,153	22,598	26,043	22,562	71,202	0.04
pyriproxyfen	5,297	5,416	3,545	14,259	49,762	50,807	34,955	135,525	0.11
spinetoram	6,253	7,186	5,508	18,947	70,294	79,516	60,816	210,626	0.09
spinosad	2,509	3,050	2,983	8,542	26,628	29,235	24,826	80,689	0.11
spirotetramat	23,719	21,001	20,387	65,107	153,437	136,234	132,088	421,758	0.15
thiamethoxam	13,726	11,354	13,247	38,327	166,681	137,602	142,365	446,648	0.09
zeta-cypermethrin*	268	250	618	1,136	5,978	8,428	21,177	35,582	0.03

*Target Pyrethroids

Table 18 reports pounds applied, acres treated, and use rates for pyrethroids and alternative AIs in citrus. Abamectin, thiamethoxam, and spirotetramat were the most widely used in terms of acres treated. Out of the pyrethroids, beta-cyfluthrin was applied on the largest number of acres. Other pyrethroids (fenpropathrin, cyfluthrin, and zeta-cypermethrin) were used on relatively fewer acres than the majority of alternative AIs in citrus.

Economic Analysis

This section presents the expected change in costs to citrus if pyrethroid insecticides became unavailable. This cost only includes the change in pesticide material costs. In the absence of any anticipated effect on yields or changes in application costs, changes in pesticide material cost are the expected changes in gross revenues. The estimated change in costs does not reflect any increase in the number of applications due to one application of pyrethroids addressing multiple pests while more than one alternative would be required to address them.

Table 19 presents representative products for each AI used on citrus in 2020–2022 and their costs per acre. The material cost per acre is the product of the average use rate (lb/ac) over this period and the price per pound. The material cost per acre ranges from $5.23 to $145.41.

Table 19: Representative Product Cost per Acre: Citrus, 2020–2022

Active ingredient	**Representative product**	**Cost per acre ($)**
abamectin	Abba Ultra Miticide/Insecticide	5.23
abamectin+cyantraniliprole	Minecto Pro	59.08
afidopyropen	Sefina Inscalis Insecticide	44.21
beta-cyfluthrin*	Baythroid Xl	5.73
bifenthrin*	Brigade Wsb Insecticide/Miticide	116.21
carbaryl	Carbaryl 4l	105.15
cyantraniliprole	Exirel Insect Control	61.15
cyfluthrin*	Tombstone Helios Insecticide	7.45
diflubenzuron	Micromite 80wgs	17.34
dimethoate	Dimethoate 400	9.85
fenpropathrin*	Danitol 2.4 Ec Spray	29.75
flupyradifurone	Sivanto Prime	45.22
imidacloprid	Admire Pro Systemic Protectant	48.44
pyrethrins	Pyganic Crop Protection Ec 5.0 Ii	66.28
pyriproxyfen	Esteem 0.86 Ec Insect Growth Regulator	90.76
spinetoram	Delegate Wg	70.42
spinosad	Entrust Sc	80.98
spirotetramat	Movento	145.41
thiamethoxam	Actara	36.61
zeta-cypermethrin*	Mustang Maxx Insecticide	14.40

*Target Pyrethroids

Following the critical use analysis methodology of Steggall et al. (2018), we make one adjustment to represent how AIs are applied in practice and their comparative efficacy across products. Citrus includes significant use of the product Minecto Pro, which contains both cyantraniliprole and abamectin. These AIs target multiple pests (PTB and NOW), but single AI products are also used (Exirel, Abba Ultra). For this reason, Minecto Pro has been separated into its own category to not duplicate area treated by these AIs and allow for analysis of each AI independently.

Table 20 shows the average acreage shares for each alternative AI used on citrus, with and without pyrethroids being available. Averaged over the three-year period 2020–2022, pyrethroids represented 15.1% of the total applications to citrus acres treated with either pyrethroids or an alternative AI. Total acres treated with insecticides do not correspond to physically unique acres because some growers may have used multiple AIs in the set considered here on the same orchard. To represent the use of alternative AIs if pyrethroids were unavailable, their use is scaled up in proportion to their acreage shares, as discussed in the methods section. The three most common alternative AIs were abamectin, thiamethoxam, and spirotetramat, together accounting for 38.7% of total citrus acres treated with pyrethroids or its alternatives, which is projected to increase to 45.5% of acres treated without pyrethroids.

Table 20: Average Annual Acreage Shares of Alternative Insecticides with and without Pyrethroids: Citrus, 2020–2022

Active ingredient	**Pyrethroids available (%)**	**Pyrethroids unavailable (%)**
abamectin	17.9	21.0
abamectin+cyantraniliprole	9.1	10.7
afidopyropen	0.6	0.7
carbaryl	0.2	0.2
cyantraniliprole	9.1	10.7
diflubenzuron	5.8	6.8
dimethoate	0.5	0.6
flupyradifurone	2.6	3.1
imidacloprid	6.9	8.1
pyrethrins	1.7	2.0
pyriproxyfen	3.2	3.8
spinetoram	5.0	5.9
spinosad	1.7	2.0
spirotetramat	10.1	11.9
thiamethoxam	10.7	12.6
Total	**84.9**	**100.0**

Note: Three-year average from 2020–2022.

Table 21 reports the average per acre costs for pyrethroids and the composite alternative. For citrus, switching to the composite alternative would increase material costs for all pyrethroids except bifenthrin. Overall, bifenthrin users would reduce their costs by 54% when switching to the alternative. Fenpropathrin users would incur the smallest cost increase (80%) and beta-cyfluthrin users would incur the largest cost increase (833%). The per acre cost could increase by 617% for cyfluthrin users, and 271% for zeta-cypermethrin users.

Table 21: Costs per Acre for Target Pyrethroids and the Composite Alternative: Citrus, 2020–2022

Active ingredient	**Cost per acre ($)**	**Cost increase for switching to composite alternative (%)**
beta-cyfluthrin	5.73	833
bifenthrin	116.21	-54
cyfluthrin	7.45	617
fenpropathrin	29.75	80
zeta-cypermethrin	14.40	271
composite alternative	53.44	-

Table 22 summarizes the annual change in total pesticide costs owing to pyrethroids being unavailable for each of the three base years. The total increase in costs would have been between $6.00 million and $6.96 million, or in percentage terms costs would have increased between 128.6% and 148.6%. Excluding bifenthrin, the cost per acre for pyrethroids is considerably less than alternative AIs. The higher cost of alternatives like cyantraniliprole will increase treatment costs for citrus growers, though this effect is mitigated by bifenthrin being considerably more expensive than alternatives.

Table 22: Change in Treatment Costs due to the Unavailability of Pyrethroids: Citrus, 2020–2022

Year	**Pyrethroids available ($)**	**Pyrethroids unavailable ($)**	**Change in cost ($)**	**Change in cost (%)**
2020	4,527,902	11,256,100	6,728,199	148.6
2021	4,666,661	10,666,884	6,000,222	128.6
2022	4,824,480	11,785,884	6,961,404	144.3

Cotton

California accounts for approximately 4.4% of the total value of U.S. cotton exports, with approximately 20% of production exported. In 2022 there were approximately 136,000 acres of cotton harvested with a total production of 434,000 bales and average yield of 1,549 pounds per acre. Total production in 2022 slightly rebounded from 374,000 bales in 2021, which was the lowest level in the past decade. Total production value for 2022 was $0.46 billion. Cotton was the state's 12th largest agricultural export commodity by export value (CDFA, 2023a).

Cotton is a perennial plant grown as an annual crop for fiber production in California. California produces two species of cotton: Upland/Acala (*Gossypium hirsutum*) and Pima/extra-long staple (*G. barbadense*). Pima is a premium, extra-long staple cotton with longer fibers than Upland cotton; it receives a higher price and is consistently grown across a much higher acreage in recent years. The total acreage of cotton in California has changed significantly over the past 20 years, with a drastic reduction in recent years, which likely has affected pest issues and approaches to pest management.

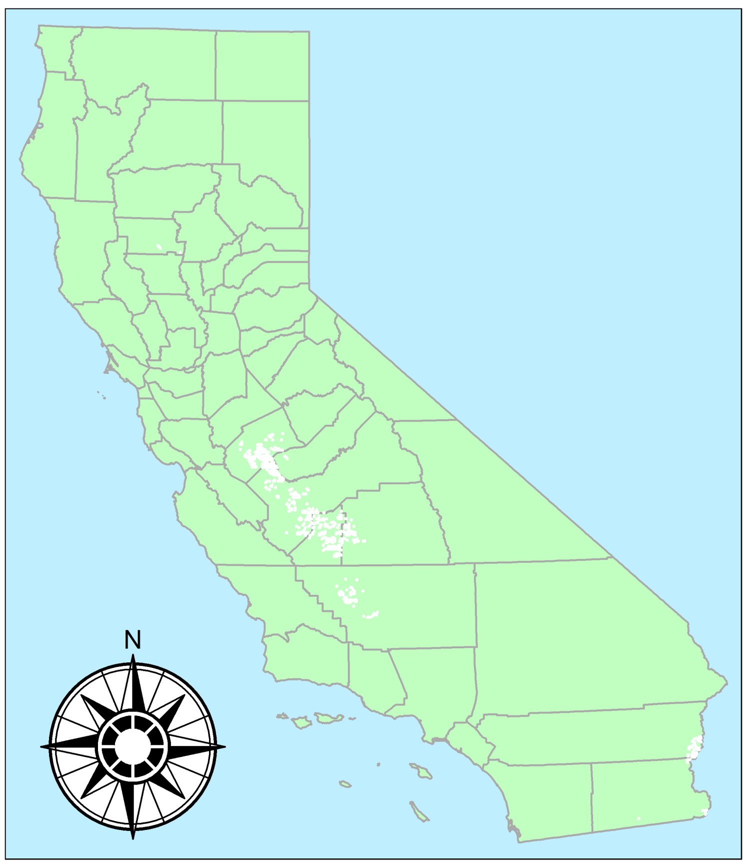


Figure 12: California Cotton Production: 2022

IPM Overview

A number of insect pests will attack cotton over the course of the season. Some pests can cause yield reductions as measured by the weight of fiber and seed at harvest by affecting germinating seedlings/plant stand and reproductive structures (squares/developing flowers, flowers, bolls). Other pests (aphids and whiteflies) can reduce economic returns by reducing cotton quality. Because cotton lint is mechanically processed and then woven into fabrics, quality is almost as important as yield, both in terms of the end product's quality and the effect of quality on ease of processing. Pyrethroids play a role in the management of a number of pests, with multiple AIs registered and used. This is for both key pests and more minor/intermittent pests. Bifenthrin has been the most used pyrethroid insecticide, followed closely by lambda-cyhalothrin. Other pyrethroids follow these two AIs in terms of degree of usage (cyfluthrin, beta-cyfluthrin, zeta-cypermethrin, fenpropathrin, and esfenvalerate). For key pests, insecticides have remained the primary method of management. However, the conservation of natural enemies can also play a role for the management of various pests, and as broad-spectrum insecticides, use of pyrethroids in cotton can run counter to natural enemy conservation. Throughout, pyrethroids are extensively used in mixtures (often with multiple AIs for the same pest), sometimes as premixes, but frequently not. In general, mixtures are more common than pyrethroid-only applications (in terms of insecticides) during the early part of the season.

Target Pests

Lygus Bugs

Lygus bugs have been a key pest in California cotton for many years and can be responsible for large reductions in yields and substantial management costs. Lygus bugs in cotton fields primarily consist of *Lygus hesperus* although *Lygus elisus* may make up a small percentage of individuals. Lygus are generalist herbivores and feed and reproduce on a wide variety of plants including a number of non-crop and crop plants. In California, populations build up in non-crop vegetation during the winter. A number of crops can also host lygus and be sources of lygus moving into cotton, which is not itself a preferred host. Alfalfa for instance is a known source of lygus, in particular when alfalfa hay is harvested although many other crops also host lygus. Lygus damages cotton by feeding on developing cotton buds (squares) and young bolls. Damaged cotton will abscise/drop damaged squares, while damage to older bolls can produce discolored lint and a reduction in quality. The reduced reproductive structures on the plant can also lead the plant to produce more vegetative growth, growing tall and spindly. This can make harvest much more difficult. Finally, damage by lygus can lead to the loss of early-developing fruiting sites, making later-developing sites much more important. This can necessitate extending the growing season for a given field, which can lead to more management issues with pests like aphids and whiteflies whose prevalence can grow over the course of the season. The severity of lygus issues in cotton fields can depend on yearly environmental conditions, in particular rainfall patterns, as well as the surrounding landscape. In terms of windows of management, the window for lygus is typically before the window for the other primary pests in cotton most years, cotton aphid and silverleaf whitefly.

Management of lygus can affect management for these pests, both because some materials used for lygus also have efficacy for these pests and because broad-spectrum insecticide use for lygus can disrupt biological control of these pests. The latter situation is also relevant for spider mites, another key pest.

A wide variety of insecticides are currently used to manage lygus, reflecting both limited highly effective tools and a variety of approaches to management. Pyrethroids are used for lygus, primarily as a component of a tank mixture as noted above. Bifenthrin is the most used pyrethroid, followed by lambda-cyhalothrin. Beta-cyfluthrin, cyfluthrin, and zeta-cypermethrin are the other pyrethroids used to target lygus. Pyrethroids are often used in cases of heavy or sustained lygus pressure. Pyrethroids are not considered primary options for lygus with other, more effective materials used. This includes both selective materials and more broad-spectrum materials. Flonicamid is an alternative to pyrethroids for lygus management and is the most-used AI for lygus. It is also very effective against cotton aphids, which is an added benefit to applications with this material for lygus. For several materials, the ability to simultaneously manage lygus and cotton aphid or whitefly can influence choice of materials for lygus. Novaluron, oxamyl, dimethoate, acephate, and clothianidin are all used for lygus to varying degrees. Indoxacarb, imidacloprid, and thiamethoxam are also at times used for lygus, frequently as components in mixtures given the limited efficacy of single AIs. Acetamiprid is sometimes used for lygus (sometimes mixed with a pyrethroid), generally later in the season and often also targeting aphids and/or whiteflies. The carbamates and organophosphates in particular (of the alternatives) run the risk of disrupting biological control. It should be noted that while clothianidin has had timing restrictions on usage, the other nitroguanidine-substituted neonicotinoids only recently (2024) had their usage restricted to before bloom. In addition, for three years sulfoxaflor, a selective material, was available for use in cotton for lygus under a Section 18 Emergency Exemption from 2017–2019, and has only recently been made available for use in 2025 under a Certificate of Emergency Registration (CDPR, 2025a). Finally, afidopyropen has been used for lygus to a degree in recent years, although prior to 2023, the majority of use was for cotton aphid and/or silverleaf whitefly.

Insecticide resistance has been a significant concern for lygus management. Resistance to pyrethroid AIs has previously been reported, and the current reliance on limited AIs (flonicamid in particular) also contributes to the threat of insecticide resistance. Alternative management strategies for lygus are generally limited. Alternate strip cutting of alfalfa hay, or leaving small unharvested strips, have been shown to limit dispersal of lygus from alfalfa fields, which can reduce lygus dispersal into cotton. However, this process interferes with harvesting efficiency and logistics, irrigation management, and management of pests within alfalfa, leading to this tactic not viewed as acceptable in most cases. The same grower may also not be managing both the alfalfa and cotton fields. In areas where safflower is also an important crop, lygus can be managed in safflower, which is a more attractive crop, before they move into cotton.

Silverleaf Whitefly

Silverleaf whitefly (*Bemesia tabaci*, biotype B) feed as adults and nymphs by sucking sap from plant phloem. Excess sugars are then excreted as sugary honeydew. In cotton, the honeydew can fall on exposed lint, reducing quality and marketability by producing "sticky cotton." Significant effects on quality can lead to substantial losses in terms of economic returns, even in the absence of direct effects on yield and this is a much greater concern. The threat of sticky cotton is not limited to management costs. If a region produces sticky cotton, cotton mills may demand a discounted price for the cotton lint or may stop buying from that region. California producers had problems with sticky cotton in the early 2000's, although there have been additional whitefly management issues in recent years (Godfrey et al., 2006). Reputation is important for California's cotton industry because producers are known for producing high-quality cotton that commands a price premium over cotton from much of the rest of the United States and other parts of the world.

A variety of AIs target silverleaf whitefly. Pyrethroids are not primary tools used to manage whiteflies. They are primarily used in the late season and/or when heavy influxes of adults into cotton fields are difficult to manage. In most cases, they are used in a tank mixture. Bifenthrin, esfenvalerate, or fenpropathrin can be mixed with an organophosphate or carbamate to achieve appreciable control. Otherwise, there are a number of alternative materials that are typically relied upon much more heavily. Buprofezin, spiromesifen, and pyriproxyfen selectively target eggs and/or nymphs when populations are low in the early- to mid-season but are not effective in the late season. Acetamiprid is used throughout much of the season as well as later in the season although there is a 28-day PHI. Flupyradifurone and afidopyropen are selective materials that are used for silverleaf whitefly during early to mid-season. Other late-season alternatives are oxamyl, naled, and acephate, although these are the materials often combined with a pyrethroid. The neonicotinoids dinotefuran and thiamethoxam can be effective early- to mid-season, although restrictions on timing of use to pre-bloom starting in 2024 have made these materials largely not applicable for whitefly.

Silverleaf whitefly is known to develop resistance to insecticides that are regularly used. Best management practices are to rely on biological control as much as possible, only resorting to chemical control if this is no longer effective enough and to rely on selective materials where possible. Additionally, silverleaf whitefly management benefits from a regional pest management approach in which cotton is planted at least half a mile upwind of other whitefly hosts, adjacent crops are promptly cleaned up, and nearby fields are kept clean of weeds in winter and spring.

Beet Armyworm (BAW)

BAWs are often present around cotton fields but only occasionally become a problem. They can destroy cotton seedlings and cause boll damage to older plants. They often establish populations on nearby weeds and then move into cotton. BAWs can feed on a variety of crops, including alfalfa, beets, beans, and many vegetables, as well as common weeds, such as pigweed and nettleleaf goosefoot. This pest is mostly kept below damaging levels by natural enemies and weather conditions. When natural enemies are disrupted and weather conditions are favorable, populations can increase.

The pyrethroids are sometimes used for BAW, including esfenvalerate and bifenthrin. Alternatives are chlorantraniliprole, novaluron, methoxyfenozide, and methomyl. Chlorantraniliprole and methoxyfenozide, are effective and do not impact natural enemies. *Bacillus thuringiensis* and spinosad are organic options to control BAW but are in such limited use (100 acres treated annually) that they are not included in this report. Conserving natural enemies and maintaining margins clean of weeds are effective strategies for BAW, along with other cotton pests.

Darkling Beetles

Darkling beetles (*Blapstinus spp.*) can be early-season pests that can damage germinating seeds and seedlings, although they are infrequent and sporadic pests. They typically invade cotton fields from nearby crop fields or adjacent weedy areas. They will cut off seedlings or girdle seedling stems. Various pyrethroids are sometimes used for darkling beetles and play a key role in their management. No cultural or alternative controls are available aside from weed management in nearby fields.

False Chinch Bug

False chinch bugs (*Nysius raphanus*) can be sporadic pests of seedling cotton. While individual bugs do little damage to cotton, large migrations of these bugs can do significant damage by severely injuring or killing young plants through their feeding. Their populations build up during the winter and spring on weeds and then migrate as these hosts dry down. No cultural or alternative controls are available aside from weed management in nearby fields.

Pyrethroid Use: 2020–2022

Pyrethroid use patterns vary annually depending on the presence of damaging pest populations, however, the majority of use occurs from early summer into the fall (Figure 13). Much of this use occurs in tank mixes of pyrethroids and other AIs.

Table 23 reports pounds applied, acres treated, and use rates for pyrethroids and alternative AIs in cotton. Flonicamid, novaluron, and imidacloprid were the AIs applied to the most acres. Bifenthrin and lambda-cyhalothrin were the pyrethroids applied to the most acres, while the other pyrethroids were not as widely applied as the major alternatives.

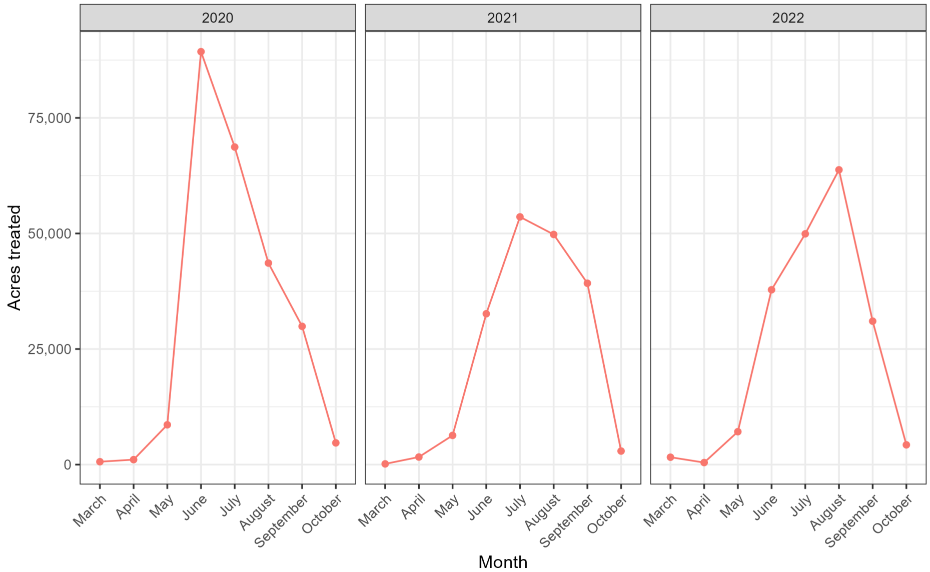


Figure 13: Monthly Use of Pyrethroids: Cotton, 2020–2022

Table 23: Annual Use of Pyrethroids and Alternative Active Ingredients: Cotton, 2020–2022

	Lbs. Applied				Acres Treated				Use Rate (lb/ac)
Active Ingredient	2020	2021	2022	Total	2020	2021	2022	Total	
acephate	15,901	14,796	19,573	50,270	17,111	16,459	20,657	54,226	0.93
afidopyropen	988	2,834	2,895	6,716	30,526	64,355	66,533	161,414	0.04
beta-cyfluthrin*	523	517	488	1,528	20,757	20,500	19,457	60,714	0.03
bifenthrin*	10,124	5,210	6,465	21,799	109,292	54,395	69,098	232,785	0.09
buprofezin	13,229	22,075	22,773	58,077	38,285	62,814	64,733	165,831	0.35
chlorantraniliprole	756	531	466	1,754	24,592	10,788	9,,306	44,686	0.04
clothianidin	2,526	1,426	1,770	5,723	32,138	17,921	21483	71541	0.08
cyfluthrin*	1,212	1,608	1,974	4,794	23,974	31,508	39,604	95,086	0.05
dimethoate	30,272	10,047	14,013	54,332	77,108	28,058	32,439	137,605	0.39
esfenvalerate*	1,206	67	51	1,325	24,255	1,342	1,268	26,865	0.05
fenpropathrin*	659	5,244	4,749	10,652	2,301	16,311	14,684	33,297	0.32
flonicamid	22,142	12,296	14,302	48,739	262,880	141,763	164,258	568,900	0.09
flupyradifurone	4,777	7,595	7,588	19,960	29,059	43,629	42,595	115,283	0.17
imidacloprid	8,054	4,917	4,423	17,394	124,760	65,269	48,983	239,011	0.07
indoxacarb	3,264	1,154	3,421	7,839	36,445	9,020	25,467	70,932	0.11
lambda-cyhalothrin*	2,313	1,778	1,592	5,683	65,868	48,429	42,568	156,865	0.04
methomyl	5,069	107	11	5,187	8,148	159	24	8,332	0.62
methoxyfenozide	513	271	1,058	1,841	3,140	1,936	6,513	11,589	0.16
naled	60,845	55,313	51,782	167,939	58,010	54,078	50,553	162,641	1.03
novaluron	10,781	5,661	7,386	23,828	138,067	74,462	101,619	314,148	0.08
oxamyl	40,085	12,634	21,124	73,842	40,451	12,584	21,139	74,174	1.00
pyriproxyfen	2,198	2,903	3,559	8,659	33,188	43,464	52,774	129,425	0.07
spiromesifen	1,278	1,155	1,947	4,380	5,258	4,586	7,779	17,623	0.25
thiamethoxam	1,191	360	1,339	2,890	19,501	7,690	21,695	48,886	0.06
zeta-cypermethrin*	2	362	228	592	79	13,776	9,274	23,129	0.03

*Target Pyrethroids

Economic Analysis

This section presents the expected change in costs to cotton if pyrethroid insecticides became unavailable. This cost only includes the change in pesticide material costs. In the absence of any anticipated effect on yields or changes in application costs, changes in pesticide material cost are the expected changes in gross revenues.

Table 24 presents representative products for pyrethroids and alternative AIs used on cotton in 2020–2022 and their material costs per acre. The material cost per acre is the product of the average use rate (lb/ac) over this period and the price per pound. The cost per acre ranges from $1.76 to $73.66.

Table 24: Representative Product Cost per Acre: Cotton, 2020–2022

Active ingredient	**Representative product**	**Cost per acre ($)**
acephate	Acephate 97up Insecticide	14.29
afidopyropen	Sefina Inscalis Insecticide	40.75
beta-cyfluthrin*	Baythroid Xl	3.86
bifenthrin*	Bifen 2 Ag Gold	5.61
buprofezin	Courier 40sc Insect Growth Regulator	39.82
chlorantraniliprole	Dupont Prevathon Insect Control	18.48
clothianidin	Belay Insecticide	13.50
cyfluthrin*	Tombstone Helios Insecticide	5.10
dimethoate	Drexel Dimethoate Lv-4	7.68
esfenvalerate*	Asana Xl Insecticide	5.19
fenpropathrin*	Danitol 2.4 Ec Spray	26.71
flonicamid	Carbine 50wg Insecticide	26.92
flupyradifurone	Sivanto Prime	52.14
imidacloprid	Wrangler Insecticide	2.92
indoxacarb	Dupont Steward Ec Insecticide	32.07
lambda-cyhalothrin*	Lamcap Ii	1.76
methomyl	Du Pont Lannate Sp Insecticide	20.75
methoxyfenozide	Intrepid 2f	25.03
naled	Dibrom 8 Emulsive	18.12
novaluron	Diamond	16.70
oxamyl	Dupont Vydate C-Lv Insecticide/Nematicide	73.66
pyriproxyfen	Knack Insect Growth Regulator	27.20
spiromesifen	Oberon 4 Sc Insecticide/Miticide	38.49
thiamethoxam	Centric 40wg	14.07
zeta-cypermethrin*	Mustang Maxx Insecticide	11.55

*Target Pyrethroids

Several adjustments were made to the products included in this analysis. Following the critical use analysis methodology of Steggall et al. (2018), such adjustments are necessary to represent how AIs are applied in practice and their comparative efficacy across products. In cotton production, two multi-AI products containing pyrethroids are widely used and required adjusting our representative product list, as they would be unavailable under the presumed regulations in their current formulations. Besiege is a multi-AI product containing a pyrethroid (lambda-cyhalothrin) and chlorantraniliprole, both of which are used extensively in cotton production. The analysis makes the conservative assumption that all chlorantraniliprole use is using the highest rate available (0.098 lb/acre) using single AI products. Leverage 360 Insecticide is another multi-AI product containing a pyrethroid (beta-cyfluthrin) and imidacloprid. Similarly, imidacloprid use from Leverage 360 is assumed to be replaced by single AI products.

Table 25: Average Annual Acreage Shares of Alternative Insecticides with and without Pyrethroids: Cotton, 2020–2022

Active ingredient	**Pyrethroids available (%)**	**Pyrethroids unavailable (%)**
acephate	1.8	2.3
afidopyropen	5.3	6.7
buprofezin	5.5	6.9
chlorantraniliprole	1.5	1.9
clothianidin	2.4	3.0
dimethoate	4.5	5.7
flonicamid	18.8	23.7
flupyradifurone	3.8	4.8
imidacloprid	7.9	10.0
indoxacarb	2.3	3.0
methomyl	0.3	0.3
methoxyfenozide	0.4	0.5
naled	5.4	6.8
novaluron	10.4	13.1
oxamyl	2.5	3.1
pyriproxyfen	4.3	5.4
spiromesifen	0.6	0.7
thiamethoxam	1.6	2.0
Total	**79.2**	**100.0**

Note: Three-year average from 2020–2022.

Table 25 shows the average acreage shares for each alternative AI with pyrethroids available and if they were not available. Averaged over the three-year period 2020–2022, pyrethroids represented 21.8% of the total applications to cotton acres treated with either pyrethroids or an alternative AI. Total acres treated with one of these insecticides does not correspond to physically unique acres because multiple applications of one or more of these insecticides may be made to a field. The three most common alternative AIs were flonicamid, novaluron, and imidacloprid, together accounting for 37.1% of total cotton acres treated.

Table 26 shows the average per-acre costs for pyrethroids and the composite alternative. For cotton, switching to the composite alternative would increase material costs for all pyrethroids except fenpropathrin. Overall, fenpropathrin users would reduce their costs by 6% when switching to the alternative. Lambda-cyhalothrin users would incur the largest cost increase (1,327%) and zeta-cypermethrin users would incur the smallest cost increase (117%). The per acre cost could increase by 550% for beta-cyfluthrin users, 392% for cyfluthrin users, 384% for esfenvalerate users, and 347% for bifenthrin users.

Table 26: Costs per Acre for Target Pyrethroids and the Composite Alternative: Cotton, 2020–2022

Active ingredient	**Cost per acre ($)**	**Cost increase for switching to composite alternative (%)**
beta-cyfluthrin	3.86	550
bifenthrin	5.61	347
cyfluthrin	5.10	392
esfenvalerate	5.19	384
fenpropathrin	26.71	-6
lambda-cyhalothrin	1.76	1,327
zeta-cypermethrin	11.55	117
composite alternative	25.09	-

Table 27 summarizes the annual change in total pesticide costs owing to pyrethroids being unavailable for each of the three base years. The total increase in costs would have been between $3.44 million and $5.06 million, or in percentage terms costs would have increased between 279.3% and 452.4%. Pyrethroids are considerably cheaper per acre than alternative AIs. Hence, prohibiting pyrethroids, particularly bifenthrin, will substantially increase treatment costs for cotton growers.

Table 27: Change in Treatment Costs due to the Unavailability of Pyrethroids: Cotton, 2020–2022

Year	**Pyrethroids available ($)**	**Pyrethroids unavailable ($)**	**Change in cost ($)**	**Change in cost (%)**
2020	1,119,490	6,184,168	5,064,678	452.4
2021	1,231,900	4,672,426	3,440,527	279.3
2022	1,245,479	4,915,575	3,670,096	294.7

Peach

California accounts for approximately 63.8% of U.S. peach gross receipts and 74.8% of total U.S. peach exports. In 2022, there were approximately 36,400 acres of peaches harvested. Total production value for 2022 was $672.8 million. Peaches were the state's 19th largest agricultural commodity by production value (CDFA, 2023a).

The three largest producing counties in California were Fresno ($348.5 million), Tulare ($115.7 million) and Stanislaus ($43.5 million), which combined accounted for 75.5% of state production. These are also the only counties where peach fell within the top ten agricultural commodities in 2022. Figure 14 depicts the geographic distribution of California's peach acreage. California produces both clingstone (mostly processing) and freestone (mostly fresh market) peaches, with a variety of cultivars for both types producing a range of fruit characteristics and harvest dates.

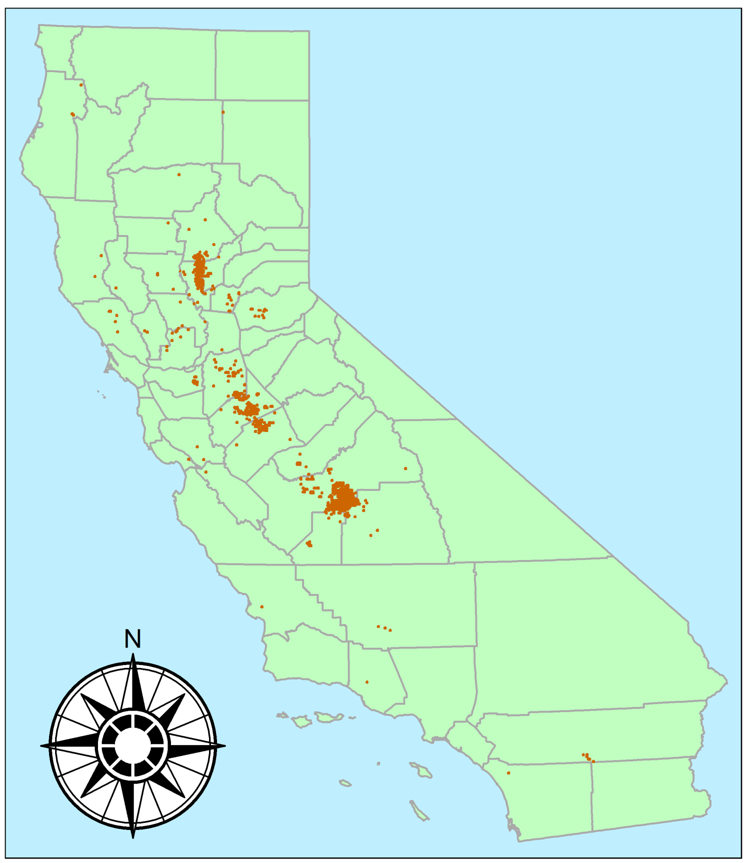


Figure 14: California Peach Production, 2022

IPM Overview

Pyrethroid insecticides are a major class of insecticides used to control lepidopteran and hemipteran pests of peaches. In 2020 to 2022, pyrethroid insecticides represented 15.4% of all insecticides applied to peaches. The principal insect pests controlled by pyrethroids are: oriental fruit moth, peach twig borer, peach tree borer, fruit tree, oblique-banded and omnivorous leafrollers, plant and stink bugs. Several pyrethroid insecticides are used to control these pests, with esfenvalerate and lambda-cyhalothrin applied most frequently. There are a number of non-pyrethroid insecticides available to control pests in peach, however the efficacy of these insecticides vary widely by pests and their adoption will be based on cost, efficacy and secondary pest control or flare-up.

Target Pests

Peach Twig Borer (PTB)

Peach twig borer (*Anarsia lineatella*), overwinters as first and second instar larvae in a hibernaculum usually in the crotch of young branches, pruning cuts or cracks in the bark. During the dormant/delayed dormant period (December through early March), the population is brooded in a susceptible stage (young larvae). A pyrethroid insecticide combined with a horticultural oil is commonly applied during this period, with esfenvalerate most commonly used. This application can also suppress San Jose scale (*Quadraspidiotus perniciosus*), green peach aphid (*Myzus persicae*), and European spider mites (*Panonychus ulmi*). There are a number of alternative insecticides to the pyrethroids. High rates of diflubenzuron, methoxyfenozide, and spinosad can be as effective in controlling of PTB as pyrethroids. Phosmet, naled, diazinon, spinetoram and chlorantraniliprole can also provide control of PTB. During the spring, PTB larvae emerge from the hibernaculum and feed on flower buds and developing shoots. When the shoots grow to sufficient size, the larvae bore into the shoots, where they complete their development and exit to pupate. Multiple applications of *Bacillus thuringiensis* applied during the bloom period can be effective against PTB; this provides an option for organic growers and conventional growers who want to avoid using pyrethroids. Adults from the overwintering generation emerge in March through April and females lay eggs on leaves and developing shoots. The larvae bore into the shoots and start feeding. This feeding causes a characteristic "flagging" or wilting of the shoots. Insecticide applications are recommended at about 400 degree days (DD) after the flight begins, which is usually in May. Lambda-cyhalothrin and esfenvalerate are the principle pyrethroid insecticides used for the 400 DD application and to a much lesser extent beta-cyfluthrin, permethrin and fenpropathrin. There are a number of alternative insecticides to the pyrethroids. These alternatives include: chlorantraniliprole, methoxyfenozide, spinosad, spinetoram, phosmet and others (Van Steenwyk et al., 2015).

Control of PTB during the remainder of the year is not usually required due to insecticide applications used for control of oriental fruit moth. In addition to alternative insecticides for control of PTB, mating disruption can be used to suppress the population. However, PTB mating disruption is not widely used because of cost as compared to alternative controls and because of the dispersal of mated PTB females from nearby almond orchards as the peach crop ripens.

Oriental Fruit Moth (OFM)

OFM (*Grapholita molesta*) is one of the most serious pest of peaches in California. OFM attack shoots in a similar manner to PTB and cause shoot "flagging." Unless the larvae are present, it is difficult to distinguish the "flagging" between the two species. However, fruit infestation is different between PTB and OFM. PTB larvae usually feed on mature fruit near the surface while OFM larvae bore to the seed and feed around the seed or stone. OFM overwinter as larvae in silken cocoons and are not affected by the dormant/delay dormant application directed for control of PTB. Adults emerge from overwintering larvae in February and March and there can be five to six generations per season. Control of OFM by insecticides requires well timed applications. Applications are timed based on DD. The first generation OFM is usually not treated because of their erratic emergence. Applications are usually applied for the second generation from May through June. The early May sprays will control PTB and early OFM while June applications are directed against OFM. Additional applications are directed against OFM during the season particularly as the fruit matures. Lambda-cyhalothrin and esfenvalerate are the principle pyrethroid insecticides used while beta-cyfluthrin, permethrin and fenpropathrin are used to a much lesser extent. There are a number of alternative insecticides to the pyrethroids. These alternatives include: diflubenzuron, chlorantraniliprole, methoxyfenozide, spinosad, spinetoram, phosmet, indoxacarb, acetamiprid, and others.

Control of OFM in large measure relies on pheromone mating disruption. In 2017 about half of the peach acreage was treated with OFM pheromone mating disruption. OFM pheromone mating disruption requires that the pheromone dispensers be placed before the beginning of the first flight in February. OFM pheromone mating disruption provides excellent control of the first two of generations. However, supplemental insecticide applications may be required as the fruit matures particularly in late maturing cultivars.

Leafrollers

There are a number of leafroller species that can damage peaches. They are: omnivorous leafroller (OLR, *Platynota stultana*), fruit tree leafroller (FTLR, *Archips argyrospila*), and obliquebanded leafroller (OBLR, *Choristoneura rosaceana*). OLR occurs in the San Joaquin Valley and can cause significant damage to peaches. However, OLR rarely causes damage to peaches in the Sacramento Valley. OLR overwinter as mature larvae on mummy fruit or in protected places in the orchard. These larvae pupate in early spring and emerge as adults in March. A generation is completed on weed hosts or young peaches in early mature cultivars. Adults from this generation emerge in May to June and lay eggs on the peach foliage. The larvae from this generation may cause considerable damage. Control of this generation should be applied against young larvae before the larvae begin leaf rolling. Once leaf rolling begins it provides a measure of protection from the insecticides for the larvae. Insecticide applications for OFM and PTB usually keep the OLR population below damaging levels and insecticide applications are typically not required. However, in some situations, control of the omnivorous leafroller may require a separate insecticide application. A pyrethroid application can be applied for control. However, BT, spinosad, spinetoram and chlorantraniliprole, or methoxyfenozide can be substituted for the pyrethroid application.

FTLR can be a serious pest of apricots and cherries in the coastal areas of California, but are rarely a problem of peaches in the San Joaquin or Sacramento valleys. FTLR overwinters as egg masses laid on branches. The eggs hatch in early spring at bloom and the young larvae feed on blossoms, leaves and young fruit. These larvae complete their development and adult emerge in May to June. These adults produce the overwintering egg masses. There is only one generation per year. Again, insecticide applications from OFM and PTB usually keep the FTLR population below damaging levels and insecticide applications are typically not required. BT, spinosad, spinetoram and chlorantraniliprole, or methoxyfenozide can be used to control FTLR.

OBLR can be a serious pest of peaches in the San Joaquin or Sacramento valleys. OBLR overwinter as larvae on the tree. These larvae pupate in early March as weather warms and emerge as adults in late March to mid-April. There are two or three generations per year in the San Joaquin or Sacramento valleys and feeding by the second and third generation may cause surface scaring of the fruit. Insecticide applications from OFM and PTB usually keep the OBLR population below damaging levels and insecticide applications are usually not required.

Tree Borers

There are a number of tree borer species that can do considerable damage particularly to young peach trees: peachtree borer (PB, *Synanthedon exitiosa*), lesser peachtree borer (LPB, *Synanthedon persicae*), American plum borer (APB, *Euzophera semifuneralis*), prune limb borer (PLB, *Bondia comonana*), and Pacific flatheaded borer (PFB *Chrysobothris mali*). Two other borer species, shoothole borer (*Scolytus rugulosus*) and branch and twig borer (*Melalgus comfertus*), are also pests of peaches. However, control of these two borer species rely on maintaining tree health, pruning out and burning infested limbs. No insecticide control is recommended.

PFB overwinter as prepupae in the infested trees. They pupate in the spring as weather warms and adult beetles emerge from April through July. The trees need to be protected for four months. PFB feeds in the cambium layer and can completely girdle young trees or individual branches. This feeding results in the death of the young trees or branches. PFB attacks sunburned trunks and weakened limbs. Control relies on tree wraps on newly planted trees or painting the trunk with diluted white paint that can be mixed with a pyrethroid insecticide.

PB and LPB attack all stone fruit but are important pests of peaches in Sacramento and Northern San Joaquin valleys. The larvae attack the crown and lower trunk of the tree and over time girdle and kill the tree; once enough trees have been killed, the orchard may need to be removed. The insecticides of choice for many years were chlorpyrifos or endosulfam. However, these insecticides have been deregistered in California. Growers currently use pyrethroid insecticides, particularly permethrin or esfenvalerate. At present, there are no effective alternatives to the pyrethroid insecticides.

Plant Bugs

There are a number of plant bug species that can damage peaches, including *Lygus hesperus*, *Lygus elisus*, and *Calocoris norvegicus*. Adults of these plant bugs feed on tender young shoots in the spring and kill the growing tip. The feeding looks similar to PTB or OFM damage but there is no mining down the shoots. They also feed on developing fruit. The damaged fruit will have a number of small dark feeding sites. As the fruit develops, the cells at the feeding site die and fruit become misshapened or "catfaced." Orchards with large plant bug populations can sustain substantial damage with significant economic loss. The plant bugs develop on weeds within the orchard or adjacent to the orchard. Very large plant bug populations can develop on adjacent crops such as alfalfa, bean, safflower or in any weedy field. When the weeds dry-up, orchard floor is mowed, or the adjacent crop is harvested, the plant bug adults will migrate to the peach orchard and cause damage within a short period of time. Thus, control must be applied immediately, and the insecticide must be fast acting and have an excellent residue period. The pyrethroid insecticides are extremely efficacious.

There are a number of alternative insecticides to replace the pyrethroids, although most are not as efficacious, fast acting nor have residual periods as long as the pyrethroids. These include high rates of the neonicotinoids acetamiprid, clothianidin, and imidacloprid, though short residual periods can limit their uses. While the use of the clothianidin, and imidacloprid has been recently restricted by DPR regulation, allowing only for treatment between post-bloom and harvest, the majority of pyrethroid use for control of plant bugs occurs post-bloom as fruit are developing and when applications are permitted. Several other materials for plant bugs are considered effective, including flonicamid, fenpropathrin, and indoxacarb, though they may have to be applied at high rates to replace pyrethroids.

Pyrethroid Use: 2020–2022

Pyrethroid insecticide use falls into three time periods: 1) Dormant/delayed dormant using predominately esfenvalerate for control of peach twig borer, 2) Early fruit development in March through May using predominately esfenvalerate and lambda-cyhalothrin for control of peach twig borer, true bugs, and oriental fruit moth, and 3) Late fruit development in May through September using lambda-cyhalothrin, esfenvalerate, beta-cyfluthrin and permethrin for control of oriental fruit moth, leafrollers, tree borers, and true bugs (Figure 15).

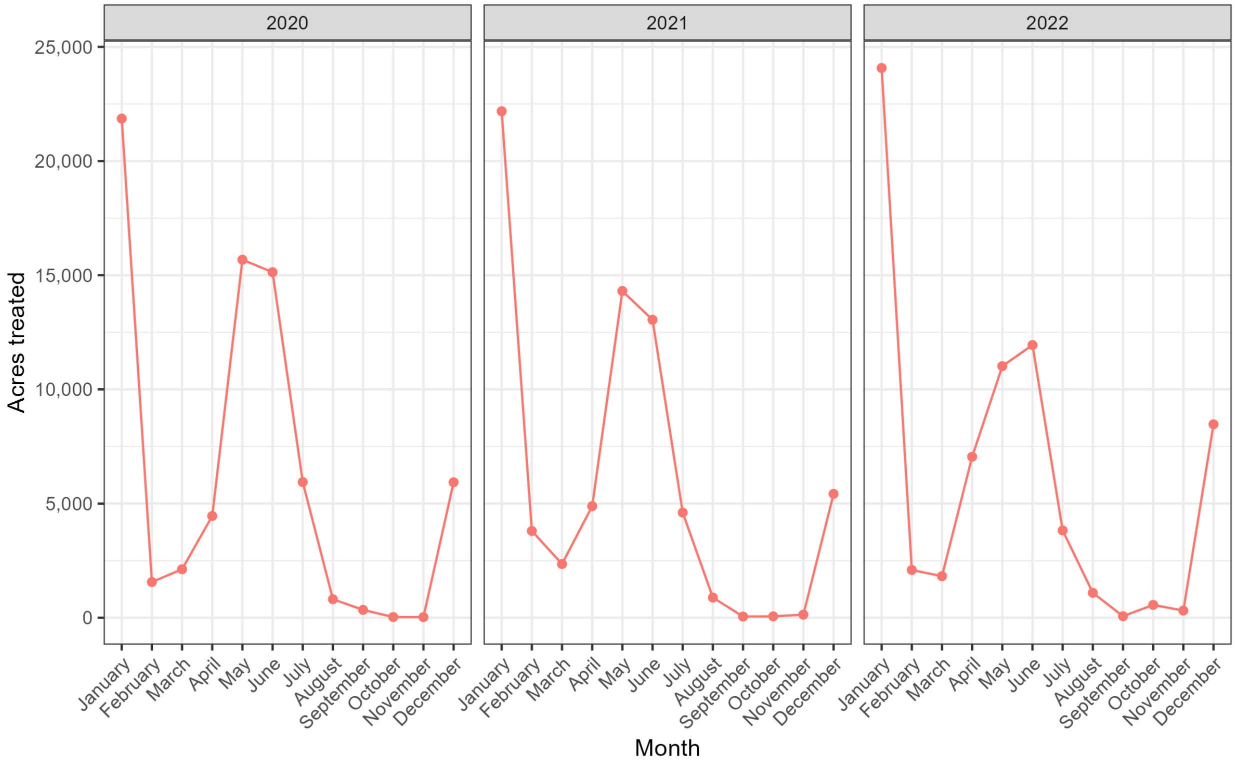


Figure 15: Monthly Use of Pyrethroids: Peach, 2020–2022

Table 28 reports pounds applied, acres treated, and use rates for pyrethroids and alternative AIs in peach. Esfenvalerate and chlorantraniliprole were the AIs applied to the most acres. Esfenvalerate and lambda-cyhalothrin were the pyrethroids applied to the most acres, while the other pyrethroids were applied far less than the major alternatives.

Table 28: Annual Use of Pyrethroids and Alternative Active Ingredients: Peach, 2020–2022

	Lbs. Applied				Acres Treated				Use Rate (lb/ac)
Active Ingredient	2020	2021	2022	Total	2020	2021	2022	Total	
acetamiprid	428	397	259	1,084	3,147	2,975	1,944	8,066	0.13
azadirachtin	104	62	76	242	4,576	2,892	3,638	11,106	0.02
bacillus thuringiensis	6,779	5,338	7,109	19,226	9,207	8,269	9,759	27,235	0.71
beta-cyfluthrin*	62	40	64	166	2,847	1,867	2,887	7,601	0.02
buprofezin	4,031	2,306	5,736	12,073	2,685	1,536	3,797	8,018	1.51
burkholderia sp.	37,308	33,310	44,846	115,464	8,205	6,444	9,718	24,367	4.74
chlorantraniliprole	2,972	3,152	2,595	8,719	34,481	36,491	31,767	102,739	0.08
cyantraniliprole	514	283	70	867	4,580	2,722	686	7,988	0.11
cyfluthrin*	41	39	38	118	1,181	1,106	1,186	3,473	0.03
diazinon	4,751	1,006	607	6,364	2,431	568	307	3,306	1.92
diflubenzuron	1,239	2,026	1,461	4,726	7,639	10,441	8,203	26,283	0.18
esfenvalerate*	2,094	2,181	2,265	6,540	34,601	36,103	36,615	107,319	0.06
fenpropathrin*	1,417	889	1,432	3,738	4,423	2,920	4,566	11,909	0.31
imidacloprid	372	361	240	973	4,916	4,032	2,716	11,664	0.08
indoxacarb	1,316	952	788	3,056	11,703	8,269	6,778	26,750	0.11
lambda-cyhalothrin*	1,115	1,028	978	3,121	29,504	26,656	25,762	81,922	0.04
methoxyfenozide	5,013	4,709	6,100	15,822	19,619	18,078	22,898	60,595	0.26
permethrin*	324	677	298	1,299	1,312	2,784	1,235	5,331	0.24
phosmet	1,158	254	68	1,480	509	137	51	697	2.12
pyriproxyfen	832	1,146	1,015	2,993	9,067	12,028	9,620	30,715	0.10
spinetoram	1,992	1,445	1,493	4,930	20,054	14,728	15,151	49,933	0.10
spinosad	1,020	1,035	406	2,461	8,306	9,279	3,861	21,446	0.11
spirotetramat	458	344	297	1,099	3,647	2,850	2,446	8,943	0.12

*Target Pyrethroids

Economic Analysis

This section presents the expected change in net revenues for peach if pyrethroid insecticides were to become unavailable. This cost consists of the change in pesticide material costs on acres previously treated with pyrethroids. We anticipate no change in application costs or yield. In the absence of any anticipated effect on yields, gross revenues will not change. Consequently, the only impact on net returns is the impact on pesticide material costs.

Table 29 presents representative products for pyrethroids and alternative AIs used on peach in 2020–2022 and their material costs per acre. The material cost per acre is the product of the average use rate (lb/ac) over this period and the price per pound. The average use rate was computed by dividing total pounds applied over the three-year period by the total acres treated. Price per pound of AI was calculated based on the product formulation and product price. The cost per acre ranges from $1.34 to $115.76.

Table 29: Representative Product Cost per Acre: Peach, 2020–2022

Active ingredient	**Representative product**	**Cost per acre ($)**
acetamiprid	Assail 70wp Insecticide	16.61
azadirachtin	Aza-Direct	63.03
bacillus thuringiensis	Dipel Df Biological Insecticide Dry Flowable	27.39
beta-cyfluthrin*	Leverage 360 Insecticide	7.99
buprofezin	Centaur Wdg Insect Growth Regulator	84.62
burkholderia sp.	Venerate Xc	72.09
chlorantraniliprole	Altacor Insect Control	42.24
cyantraniliprole	Minecto Pro	48.77
cyfluthrin*	Tombstone Helios Insecticide	3.40
diazinon	Diazinon Ag 500	39.04
diflubenzuron	Dimilin 2l	24.67
esfenvalerate*	Asana Xl Insecticide	6.41
fenpropathrin*	Danitol 2.4 Ec Spray	26.21
imidacloprid	Wrangler Insecticide	3.35
indoxacarb	Avaunt Evo Insect Control	60.80
lambda-cyhalothrin*	Silencer	1.34
methoxyfenozide	Intrepid 2f	41.14
permethrin*	Perm-Up 3.2 Ec Insecticide	7.17
phosmet	Imidan 70-W	69.75
pyriproxyfen	Seize 35 Wp Insect Growth Regulator	41.82
spinetoram	Delegate Wg	77.28
spinosad	Entrust Sc	87.79
spirotetramat	Movento	115.76

*Target Pyrethroids

In peach production, Leverage 360 Insecticide is a multi-AI product containing a pyrethroid (beta-cyfluthrin) and imidacloprid. Its use rate for beta-cyfluthrin is equivalent to other beta-only products (such as Baythroid XL), but is half the rate of imidacloprid products. For this reason, Leverage 360 is retained as the representative product for beta-cyfluthrin, but the second-highest use product (Wrangler) is used as the representative product for imidacloprid. This results in a conservative over-estimate of imidacloprid use, given acreage treated by a lower-use-rate product (Leverage) is contributing to our estimates with the costs of a full-rate product. However, this better represents the reality of pyrethroid unavailability, as multi-AI applications containing pyrethroids would likely be replaced by single-AI products like Wrangler.

Table 30 provides the acreage shares for the alternatives used on peach from 2020 to 2022. The second column reports the acreage share treated with each alternative AI when pyrethroids are available. Averaged over the three-year period 2020–2022, pyrethroids represented 33.6% of the total applications to peach acres treated with either pyrethroids or an alternative AI. The third column reports the share of each alternative in the composite alternative used to replace applications of unavailable pyrethroids. The most applied alternative AI is chlorantraniliprole, accounting for 23.9% of peach acres treated with pyrethroids and alternative insecticides.

Table 30: Average Annual Acreage Shares of Alternative Insecticides with and without Pyrethroids: Peach, 2020–2022

Active ingredient	**Pyrethroids available (%)**	**Pyrethroids unavailable (%)**
acetamiprid	1.2	1.9
azadirachtin	1.7	2.6
bacillus thuringiensis	4.2	6.3
buprofezin	1.2	1.9
burkholderia sp.	3.8	5.7
chlorantraniliprole	15.9	23.9
cyantraniliprole	1.2	1.9
diazinon	0.5	0.8
diflubenzuron	4.1	6.1
imidacloprid	1.8	2.7
indoxacarb	4.1	6.2
methoxyfenozide	9.4	14.1
phosmet	0.1	0.2
pyriproxyfen	4.7	7.1
spinetoram	7.7	11.6
spinosad	3.3	5.0
spirotetramat	1.4	2.1
Total	**66.4**	**100.0**

Note: Three-year average from 2020–2022.

Table 31 shows costs per acre for target pyrethroids and the composite alternative. For peach, switching to the composite alternative would increase material costs. The per acre cost would increase by 1,389% for cyfluthrin users, 691% for esfenvalerate, 607% for permethrin users, 534% for beta-cyfluthrin user, 93% for fenpropathrin users, and 3,694% for lambda-cyhalothrin users.

Table 31: Costs per Acre for Target Pyrethroids and the Composite Alternative: Peach, 2020–2022

Active ingredient	Cost per acre ($)	Cost increase for switching to composite alternative (%)
beta-cyfluthrin	7.99	534
cyfluthrin	3.40	1389
esfenvalerate	6.41	691
fenpropathrin	26.21	93
lambda-cyhalothrin	1.34	3,694
permethrin	7.17	607
composite alternative	50.69	-

Table 32 summarizes the annual change in total pesticide costs owing to pyrethroids being unavailable for each of the three base years. The total increase in costs would have been between \$3.24 million and \$3.33 million, or in percentage terms costs would have increased between 762% and 847.1% on acreage treated with pyrethroids that would have been prohibited. These estimates exclude any increase in the use of mating disruption for OFM. As with the other focal crops, pyrethoids being considerably cheaper than alternative AIs results in a large increase in treatment costs for peach growers if pyrethroids were not available. However, the cost increase is slightly mitigated by the relatively small use of AIs other than burkholderia sp.

Table 32: Change in Treatment Costs due to the Unavailability of Pyrethroids: Peach, 2020–2022

Year	Pyrethroids available ($)	Pyrethroids unavailable ($)	Change in cost ($)	Change in cost (%)
2020	413,440	3,744,529	3,331,090	805.7
2021	382,350	3,621,254	3,238,905	847.1
2022	424,892	3,662,592	3,237,702	762.0

Pistachio

California accounts for almost all of U.S. pistachio production, and is the world's largest producer and exporter – globally accounting for 41% of production and 70.8% of exports (USDA Foreign Agricultural Service, 2024).

In 2022 there were approximately 428,000 acres of bearing pistachio orchards. Production value is down by approximately 25.4% from 2021, with total value over $1.86 billion. Yield falling from 2,820 in 2021 to 2,060 in 2022 accounts for most of the reduction in total production value, while the pistachio price only fell from $2.16 to 2.11 per pound in 2022 and acreage increased from 409,000 to 428,000. Pistachios were the state's eighth largest agricultural commodity by production value (CDFA, 2023a).

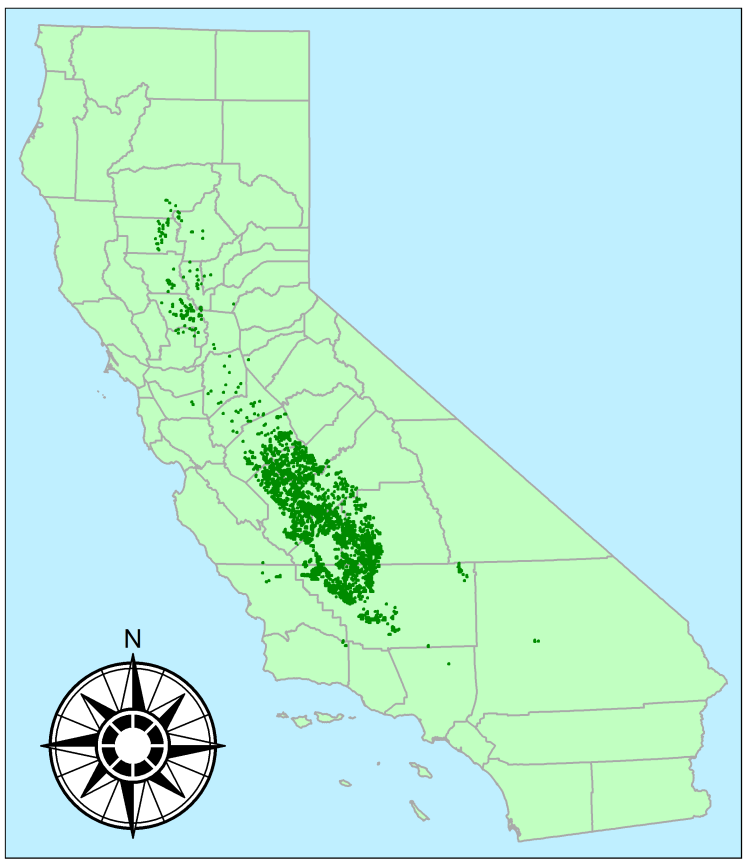
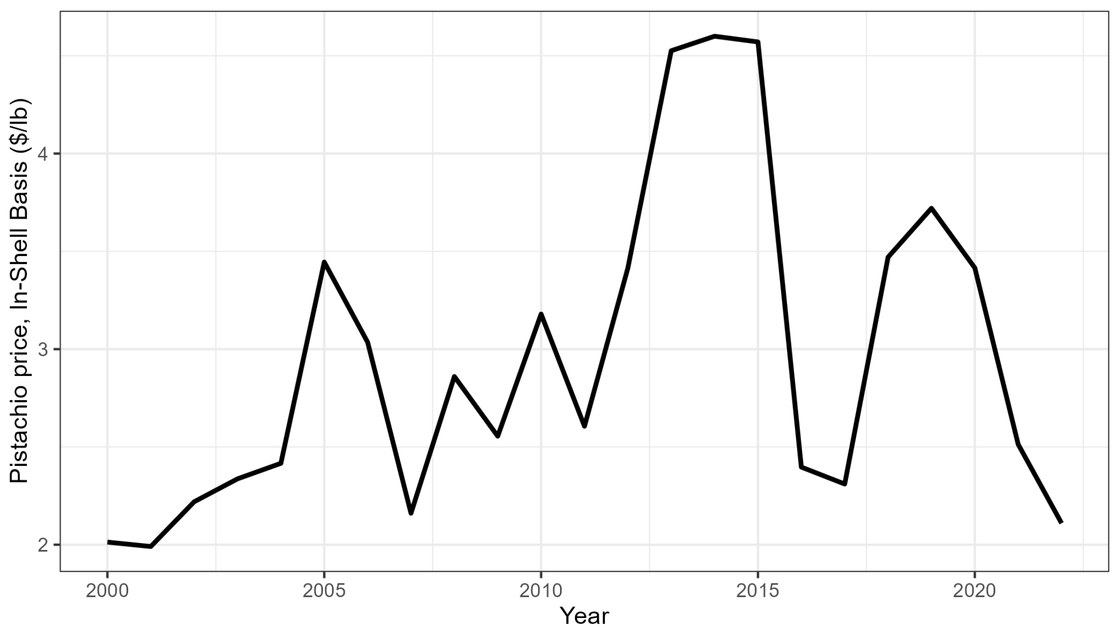


Figure 16: California Pistachio Production, 2022

About $2.2 billion worth of pistachios were exported in 2022, making pistachio California's third most important export agricultural commodity by value. By value of production, pistachios were the largest agricultural export commodity to China/Hong Kong and the second largest export to the European Union (CDFA, 2023b).

The three largest producing counties in California were Fresno ($689.88 million), Kern ($649.16 million) and Tulare ($443.15 million), which combined accounted for 74.4% of state production. Pistachios fell within the top ten agricultural commodities in nine counties (Butte, Fresno, Glenn, Kern, Kings, Madera, Tehama, Tulare, and Yolo) and within the top four agricultural commodities in three counties (Fresno, Kings, and Madera). Figure 16 depicts the geographic distribution of California's pistachio acreage.

Since 2000, the price per pound of in-shell pistachios has fluctuated between $2.00/lb in 2000 and $4.55/lb in 2014. Figure 17 graphs the price per pound for in-shell pistachio from 2000–2022. As with almonds, the price of pistachios peaked in 2014 during the height of the 2011–2017 drought.



Note: Prices are in real dollars (2022) using the Producer Price Index (PPI) for commodities (U.S. BLS, 2022).

Figure 17: Pistachio Price (In-Shell Basis): 2000–2022

IPM Overview

Pistachio production relies heavily on pyrethroids, with these compounds representing 41.7% of acreage treated with insecticides from 2020 to 2022 (CDPR, 2023).

The pyrethroids used in pistachio orchards include zeta-cypermethrin, beta-cyfluthrin, bifenthrin, cyfluthrin, deltamethrin, fenpropathrin, lambda-cyhalothrin, and permethrin. Of these, bifenthrin and lambda-cyhalothrin are the most frequently utilized, accounting for 83% of total pyrethroid use (33% bifenthrin, 50% lambda-cyhalothrin). Most of the state's pistachios receive at least one pyrethroid application annually.

Over the past 10 years there has been a shift within the pyrethroids used in tree nuts, including pistachio, with permethrin use notably dropping significantly (from 16% to 8% of pyrethroid-treated pistachio acreage). This has been offset by increased use of lambda-cyhalothrin (from 37% to 50%) and consistent use of bifenthrin (from 33% to 32%). This is likely the result of both lambda-cyhalothrin and bifenthrin moving off patent and thus becoming significantly cheaper. Furthermore, these two AIs are next-generation pyrethroids that have increased efficacy over permethrin.

Target Pests

Navel Orangeworm (NOW)

NOW is arguably the most important insect pest of pistachio. Females oviposit directly onto the nuts, and the larvae feed on the nut meats. This feeding not only reduces crop yield and quality, but also facilitates the introduction and growth of *Aspergillus* spp. fungi that produce aflatoxin, a known human carcinogen that is heavily regulated in key markets. The ability of NOW to access nut meats is regulated by hull integrity, since early instar larvae are unable to penetrate the hull, such that in years with high integrity crop infestation by NOW tends to be generally reduced.

NOW overwinter as larvae or pupae in remnant "mummy" nuts that are left behind following harvest. In the spring, overwintered adults utilize these mummies as a reproductive substrate for first generation moths, since all tree nuts are still relatively intact and thus not vulnerable to NOW infestation. Almonds are the first nut to become vulnerable to NOW, with hull-split occurring in early July. These new crop nuts are a much better host, and more abundant, and as such NOW populations begin to significantly build in July and beyond, especially as pistachio hull integrity declines in August, and these nuts then become available as a host as well. NOW populations can also make use of early-split pistachio ("pea splits") in July, which occur ahead of hull-slip which is usually closer to August.

Modern NOW management in pistachio consists of (1) winter sanitation, (2) monitoring, (3) well-timed insecticide sprays, (4) timely harvest, and more recently, (5) mating disruption.

Sanitation is the foundation of NOW management. During the winter growers are strongly advised to remove or destroy overwintered remnant "mummy" pistachios from their orchards. Sanitation typically involves shaking trees or hand poling to bring all mummies onto the orchard floor, where they can then be gathered into windrows and destroyed via disking or flail mowing. While this management strategy is strongly recommended, not all growers are able to effectively sanitize due to the costs and/or availability of labor and equipment. Even in the absence of these barriers, poor weather and/or orchard conditions (wet soils) can also impede timely access by heavy equipment and/or field crews to carry out sanitation. Finally, the small size and durability of pistachios make them especially difficult to destroy relative to other, larger tree nuts such as almonds and walnuts.

Monitoring is important to know when to expect peak NOW activity. Monitoring with egg traps can allow growers to determine a biofix and begin calculating degree days in order to estimate peak NOW flight and, most importantly, egg-laying activity. This can be supplemented with the use of flight traps with pheromone lures to monitor adult male activity.

If a spray is warranted, insecticides are typically applied around hull-slip (August) and thereafter, when the new crop pistachios become susceptible to NOW infestation. The AIs that are most commonly applied for NOW include pyrethroids (bifenthrin and lambda-cyhalothrin), insect growth regulators (methoxyfenozide), and diamides (chlorantraniliprole). It is important to note here that recent studies have documented NOW resistance to the pyrethroid bifenthrin. Most growers utilize a two-spray program starting in August that includes bifenthrin followed by either methoxyfenozide or chlorantraniliprole. The order and combination of these three products can vary across orchards, and in some cases growers may put on a spray that is a mix of bifenthrin and one of the latter two AIs. Chlorantraniliprole is thought to have a shorter residual than methoxyfenozide, and so in some cases repeat applications of chlorantraniliprole are used to compensate for this. Lambda-cyhalothrin is also sometimes used as part of the two-spray NOW program later in the season, but the primary pyrethroid used for NOW control is bifenthrin. The UC IPM program has been promoting methoxyfenozide and chlorantraniliprole as lower toxicity products for control of NOW. Over the past ten years, methoxyfenozide has consistently accounted for about 9% of total applied acres while chlorantraniliprole has increased from 6% to 15%. These two products are almost exclusively used for NOW. Increased use of chlorantraniliprole is related to the development of generics for this AI as well as the development of resistance by NOW to pyrethroids.

Timely harvest is simply a logistical effort to minimize the time that ready-to-harvest pistachios remain in the orchard, since the probability of infestation steadily rises over time as NOW populations build up over the season, especially with the third and fourth flights that occur in August and September.

Mating disruption can also be an effective tool for NOW management, although the costs ($120-170/acre) and area-requirements (i.e., works better when used over larger contiguous areas) do not necessarily work for smaller growers or in years when operating budgets are reduced due to low crop prices. There are currently four commercially available products that are all about equally effective when used in combination with the aforementioned cultural and chemical control strategies. More recently a cheaper flowable mating disruption product has been introduced, although research is still underway to determine efficacy and efficient use. Continuing research on mating disruption would benefit NOW control in pistachio and other tree nuts.

Pistachio growers do have a suite of alternative options for NOW control outside of pyrethroids, and as mentioned some NOW populations are now known to be resistant to pyrethroids. That said, pyrethroids are still a critical tool for pistachio growers, especially when dealing with large and persistent NOW populations, and restricting their use in this crop would present a significant and critical challenge to growers and could accelerate the development of NOW resistance to other AIs.

Leaffooted Bugs (LFB)

While *Leptoglossus clypealis*, *L. occidentalis*, and *L. zonatus* can all be found in pistachio, the most dominant and frequently encountered species over the last decade has been *L. zonatus*. Adult LFB overwinter in sheltered areas (e.g., natural habitats, citrus and olives, residential areas, landscape plantings etc.) and in the spring adults disperse into orchards to feed and reproduce. Typically LFB first attack almonds, followed by pistachios later in the season, and finally arrive on pomegranates in the fall. This is not a strict delineation, and LFB can make use of a wide range of hosts, both other crops (tomatoes, corn, cucumber, etc.) and non-crop (various weedy vegetation). In pistachio, early in the season, LFB cause damage to the developing nuts that mostly results in nut drop or epicarp lesion. In the late season, these pests cause kernel necrosis; the only external signs are little brown pinpricks but inside the nutmeat is discolored, has an off-flavor, and is susceptible to fungus. Later in the season, after shell hardening in June, LFB feeding can cause kernel necrosis and/or stigmatomycosis. Populations of *L. zonatus* have become more common in tree nuts over the past 10 years, most likely due to the reduced use of organophosphates for NOW, which probably produced secondary control of true bugs. Monitoring LFB in pistachio requires beat sampling the tree canopy, which is a time consuming and labor-intensive process. Even if carried out properly, there are no clear economic thresholds for these insects, and many growers make treatment decisions based on relative experience over the years in a given orchard. There are no good biological or cultural controls for these insects, and so growers must primarily rely on chemical controls, all of which are pyrethroids. There are no proven alternatives to pyrethroids for LFB management, meaning any restrictions on pyrethroids would have significant negative impacts on plant bug control in pistachio.

Stink Bugs

There are several stink bugs that can be found in pistachios, this includes the Uhler stink bug (Pentatomidae: *Chlorochroa uhleri*), green stink bug (*Chinavia hilaris*, formerly *Acrosternum hilare*), and the redsholdered stink bug (*Thyanta pallidovirens* and *T. custator acerra*). Stink bugs lay their eggs in clusters on the twigs, leaves and nuts. These insects have pierce-suck mouthparts, and like LFB early season feeding on developing nuts can lead to epicarp lesion, while feeding later in the season can cause kernel necrosis and stigmatomycosis. Stink bugs can develop around pistachio orchards, often in weedy field margins, and then migrate in later in the season as weedy vegetation dries down or is eliminated. For this reason, they can be either early or late season pests. Similarly to LFB, sampling for stink bugs is costly and labor-intensive and there are no effective biological, cultural, or non-pyrethroid chemical control options.

Small Plant Bugs (Miridae)

There are a variety of small plant bugs that attack a pistachio depending on the orchard location and time of year. These include California buckeye bug (*Neurocolpus longirostris*), Calocoris bug (*Calocoris norvegicus*), Phytocoris bug (*Phytocoris californicus*, *P. relativus*), Western tarnished plant bug (*Lygus hesperus*), and *Psallus vaccinicola*. Due to their small size, this group only causes damage from bloom through shell hardening. This approximates to roughly April to the end of May; however, during cool springs shell hardening is delayed and injury from plant bugs may be extended until June. Damage from these insects is similar to that caused by LFB and stink bugs in the early season. Small nuts turn black and fall off the tree. Larger nuts turn brown and shrivel. As with LFB and stink bugs, sampling for small plant bugs is costly and labor-intensive and there are no effective biological, cultural, or non-pyrethroid chemical control options. There are no alternatives to pyrethroids for small plant bug management.

Pyrethroid Use: 2020–2022

In pistachio, pyrethroids are primarily applied at two key points in the season – spring (May) and summer (August) (Figure 18). Spring applications around May primarily consist of lambda-cyhalothrin, which targets stink bugs (Pentatomidae: *Chlorochroa uhleri*, *Chinavia hilaris*, and *Thyanta pallidovirens*), small plant bugs (Miridae: *Lygus hesperus*, *Phytocoris* spp., and *Calocoris norvegicus*) and leaffooted plant bugs (Coreidae: *Leptoglossus* spp.) (LFB). Summer applications around August mostly utilize bifenthrin for navel orangeworm (*Amyelois transitella*) (NOW) control, which can be used in combination with methoxyfenozide and/or chlorantraniliprole.

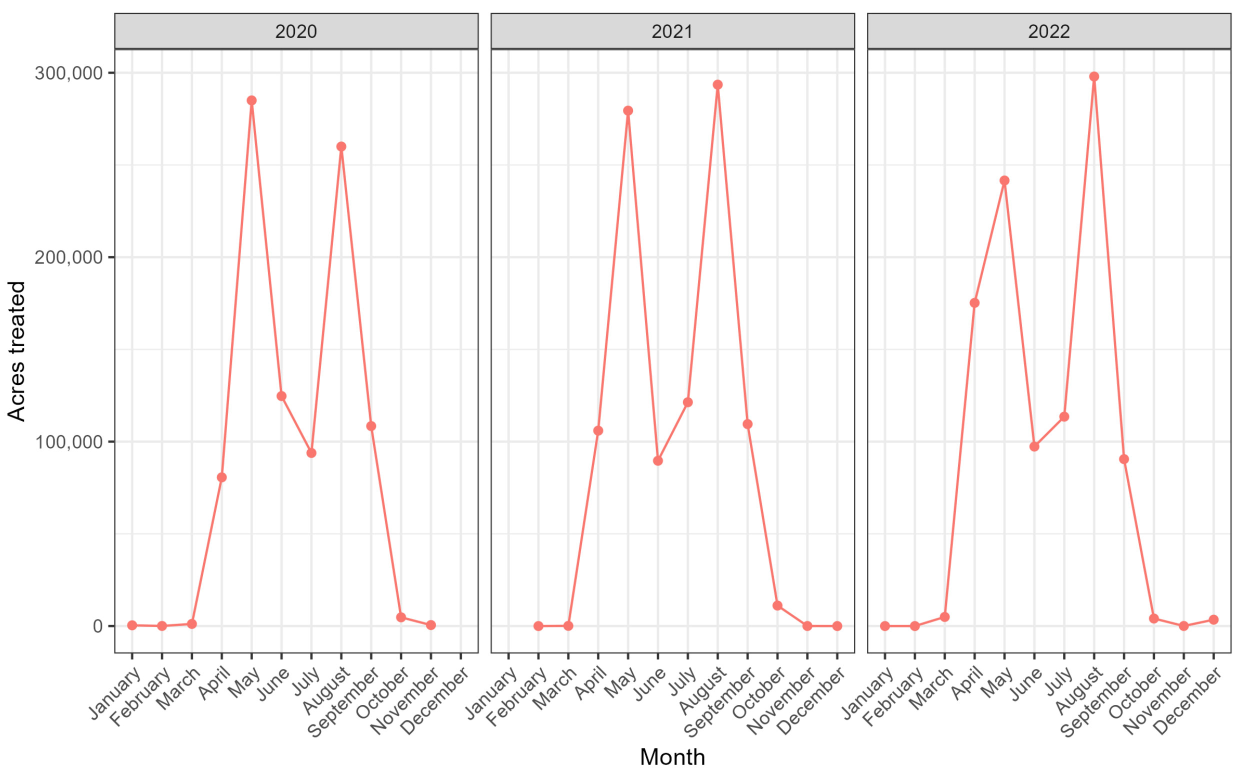


Figure 18: Monthly Use of Pyrethroids: Pistachio, 2020–2022

Table 33: Annual Use of Pyrethroids and Alternative Active Ingredients: Pistachio, 2020–2022

	Lbs. Applied				Acres Treated				Use Rate (lb/ac)
Active Ingredient	2020	2021	2022	Total	2020	2021	2022	Total	
(z,z)-11,13-hexadecadienal	639	695	1,309	2,644	68,874	81,343	116,390	266,606	0.01
beta-cyfluthrin*	993	803	778	2,574	46,647	37,338	35,867	119,852	0.02
bifenthrin	61,435	61,748	60,585	183,768	330,170	327,102	323,714	980,986	0.19
chlorantraniliprole	26,266	28,460	28,555	83,281	331,484	360,720	342,701	1,034,905	0.08
cyfluthrin*	501	1,195	2,114	3,810	12,611	29,031	50,099	91,741	0.04
fenpropathrin*	7,148	7,692	8,776	23,616	19,077	19,931	21,773	60,782	0.39
lambda-cyhalothrin*	19,518	20,245	20,798	60,562	470,931	508,714	519,983	1,499,628	0.04
methoxyfenozide	93,027	96,580	96,551	286,158	245,450	247,554	247,943	740,946	0.39
permethrin*	22,979	23,941	20,141	67,062	79,124	84,931	69,241	233,296	0.29
zeta-cypermethrin*	33	100	196	330	906	3,630	7,969	12,505	0.03

*Target Pyrethroids

Table 33 reports pounds applied, acres treated, and use rates for pyrethroids and alternative AIs in pistachio. Lambda-cyhalothrin, chlorantraniliprole, and bifenthrin were the most widely used in terms of acres treated. Out of the pyrethroids, lambda-cyhalothrin was applied on the largest number of acres. Pyrethroid use in pistachio range from the most-applied AI (lambda-cyhalothrin) to the least-applied (zeta-cypermethrin).

Economic Analysis

This section presents the expected change in net revenues for pistachios if pyrethroid insecticides were to become unavailable. Both pest management costs and gross revenues may be affected.

Pest management costs. This cost consists of the change in pesticide material costs on acres previously treated with pyrethroids and reduced revenues due to lower yields. We anticipate no change in application costs.

Table 34 presents representative products for pyrethroids and alternative AIs used on pistachio in 2020–2022 and their material costs per acre. The material cost per acre is the product of the average use rate (lb/ac) over this period and the price per pound. The average use rate was computed by dividing total pounds applied over the three-year period by the total acres treated. Price per pound of AI was calculated based on the product formulation and product price. The cost per acre ranges from $3.30 to $60.85.

Table 34: Representative Product Cost per Acre: Pistachio, 2020–2022

Active ingredient	**Representative product**	**Cost per acre ($)**
(z,z)-11,13-hexadecadienal	Checkmate Now-F	32.77
beta-cyfluthrin*	Baythroid Xl	3.30
bifenthrin*	Sniper	14.84
chlorantraniliprole	Altacor Insect Control	40.06
cyfluthrin*	Tombstone Helios Insecticide	4.20
fenpropathrin*	Danitol 2.4 Ec Spray	32.44
lambda-cyhalothrin*	Warrior Ii With Zeon Technology	12.23
methoxyfenozide	Intrepid 2f	60.85
permethrin*	Perm-Up 3.2 Ec Insecticide	8.47
zeta-cypermethrin*	Mustang Maxx Insecticide	11.89

*Target Pyrethroids

As in almond, the top used mating disruption pheromone product in pistachio, Checkmate Now-F ((z,z)-11,13-hexadecadienal), has a significantly lower use rate than other (z,z)-11,13-hexadecadienal containing products. To account for this, price calculations have been manually changed to use the pistachio-average Checkmate Now-F use rate of 0.002204484 lb/acre.

Table 35 provides the acreage shares for the alternatives used on pistachio from 2020 to 2022. The second column reports the acreage share treated with each alternative AI when pyrethroids are available. Averaged over the three-year period 2020–2022, pyrethroids represented 59.5% of the total applications to pistachio acres treated with either pyrethroids or an alternative AI. The most applied alternative AI is chlorantraniliprole, accounting for 20.5% of pistachio acres treated with pyrethroids or its alternatives. The third column reports the share of each alternative in the composite alternative used to replace applications of unavailable pyrethroids.

Table 35: Average Annual Acreage Shares of Alternative Insecticides with and without Pyrethroids: Pistachio, 2020–2022

Active ingredient	**Pyrethroids available (%)**	**Pyrethroids unavailable (%)**
(z,z)-11,13-hexadecadienal	5.3	13.1
chlorantraniliprole	20.5	50.7
methoxyfenozide	14.7	36.3
Total	**40.5**	**100.0**

Note: Three-year average from 2020–2022.

Table 36 shows costs per acre for target pyrethroids and the composite alternative. For pistachio, switching to the composite alternative would increase material costs. The per acre cost would increase by 1,316% for beta-cyfluthrin users, 1,011% for cyfluthrin users, 451% for permethrin users, 292% for zeta-cypermethrin users, 281% for lambda-cyhalothrin users, 214% for bifenthrin users, and 44% for fenpropathrin users.

Table 36: Costs per Acre for Target Pyrethroids and the Composite Alternative: Pistachio, 2020–2022

Active ingredient	Cost per acre ($)	Cost increase for switching to composite alternative (%)
beta-cyfluthrin	3.30	1,315.7
bifenthrin	14.84	214.4
cyfluthrin	4.20	1,010.7
fenpropathrin	32.44	43.8
lambda-cyhalothrin	12.23	281.4
permethrin	8.47	450.9
zeta-cypermethrin	11.89	292.3
composite alternative	46.65	-

Table 37 summarizes the annual change in total pesticide costs owing to pyrethroids being unavailable for each of the three base years. The total increase in costs would have been between $32.59 million and $35.11 million. In percentage terms costs would have increased between 268.0% and 272.6% on acreage treated with pyrethroids that would have been prohibited. As with the other focal crops, pyrethoids being considerably cheaper than alternative AIs (at most half the price of the composite alternative, with the exception of fenpropathrin) results in a large increase in treatment costs for pistachio growers if pyrethoids were not available.

Table 37: Change in Treatment Costs due to the Unavailability of Pyrethroids: Pistachio, 2020–2022

Year	Pyrethroids available ($)	Pyrethroids unavailable ($)	Change in cost ($)	Change in cost (%)
2020	12,163,816	44,757,671	32,593,855	268.0
2021	12,727,936	47,146,667	34,418,730	270.4
2022	12,877,619	47,984,891	35,107,272	272.6

Change in gross revenues. With a complete removal of pyrethroids, no effective management strategies for LFB remain, likely resulting in significant yield losses for pistachio producers. We projected yield loss associated with LFB by identifying pistachio acreage treated with pyrethroids between June 15th and August 31st (applications during this period are almost exclusively for LFB) and calculated a 25% yield loss on that acreage.

The change in total revenue depends on how the price of pistachio changes in response to a change in quantity. The own-price elasticity of demand represents the relationship between the change in quantity and the change in price. If an elasticity is smaller in magnitude than -1 (inelastic), an increase in price is associated with a less than proportionate increase in the quantity demanded, and total revenue increases. If it is larger than -1 in magnitude (elastic), then the decrease in the quantity demanded is larger than proportionate than the change in price, and total revenue falls. If the own-price elasticity of demand is -1, then gross revenue remains the same. The largest gross revenue decline occurs when demand is perfectly elastic (i.e., elasticity = $-\infty$). In this case, there is no increase in price when the quantity produced declines. Perfectly elastic demand corresponds to a case where California production is a small share of total market production and thus has little influence on the market-clearing price. Pistachio is exclusively produced in California and was the second highest-valued export crop in 2022 (CDFA, 2023a). Reductions in California's supply would likely increase the market-clearing price. We apply two own-price elasticity estimates for pistachio: an imperfect elasticity (-1.6) and a perfect (infinite) elasticity. The imperfectly elastic estimate is from Trilnick and Zilberman (2021).

If pyrethroids were available, pistachio farmers would receive the price and yield reported in the 2022 California Agricultural Statistics (CDFA, 2023a). Table 38 reports the outcomes under the two own-price demand elasticities: the perfectly elastic scenario (no price change, Column 4, Table 38) and the imperfect elastic scenario with increasing price (Column 5, Table 38), which uses an own-price elasticity of -1.06 resulting in an approximately 10.8% larger price than the perfectly elastic scenario..

Table 38: Annual Yield and Price for California Pistachio

Yield (tons)		**Price (\$/ton)**		
Pyrethroids available	**Pyrethroids unavailable**	**Pyrethroids available**	**Pyrethroids unavailable**	
			Perfectly elastic Elasticity=-∞	**Imperfectly elastic Elasticity=-1.06**
1.03	0.83	4,220.00	4,220.00	4,674.82

Gross revenue is the product of output (yield $\times$ acreage) and the realized price. Table 39 reports the estimated change in gross revenues for California pistachio if pyrethroids were unavailable. Under the expected 25% yield loss for the acres treated between June 15 and August 31, the magnitude of the change in gross revenue change depends on the elasticity of demand. Under the perfectly elastic scenario (Elasticity = $-\infty$), gross revenue losses range from \$290.6 million to \$325.2 million, or 18.4% to 20.0%. Under the imperfectly elastic scenario, gross revenue losses range from \$152.1 million to \$184.6 million, or 9.7% to 11.3%.

Table 39: Change in Gross Revenue due to 25% Yield Loss on Acreage Treated with Pyrethroids from the Unavailability of Pyrethroids, 2020–2022

Year	Gross revenue with pyrethroids available ($)	Gross revenue with pyrethroids unavailable ($)	Change in gross revenue ($)	Change in gross revenue (%)
Perfectly elastic: Elasticity = -∞				
2020	1,575,830,056	1,285,197,124	290,632,931	18.4
2021	1,629,515,608	1,304,305,875	325,209,732	20.0
2022	1,717,830,218	1,392,975,103	324,855,115	18.9
Imperfectly elastic: Elasticity = -1.60				
2020	1,575,830,056	1,423,713,184	152,116,872	9.7
2021	1,629,515,608	1,444,881,440	184,634,168	11.3
2022	1,717,830,218	1,543,107,265	174,722,953	10.2

Note: Reported gross revenue reflects harvested acreage treated with pyrethroids during the 2020–2022 period.

Strawberry

California production represents 85.3% of the total value of strawberry produced in the United States (USDA National Agricultural Statistics Service, 2024a). The total value of strawberry production in California in 2022 was $2.97 billion. Figure 19 depicts the geographic distribution of California's strawberry acreage.

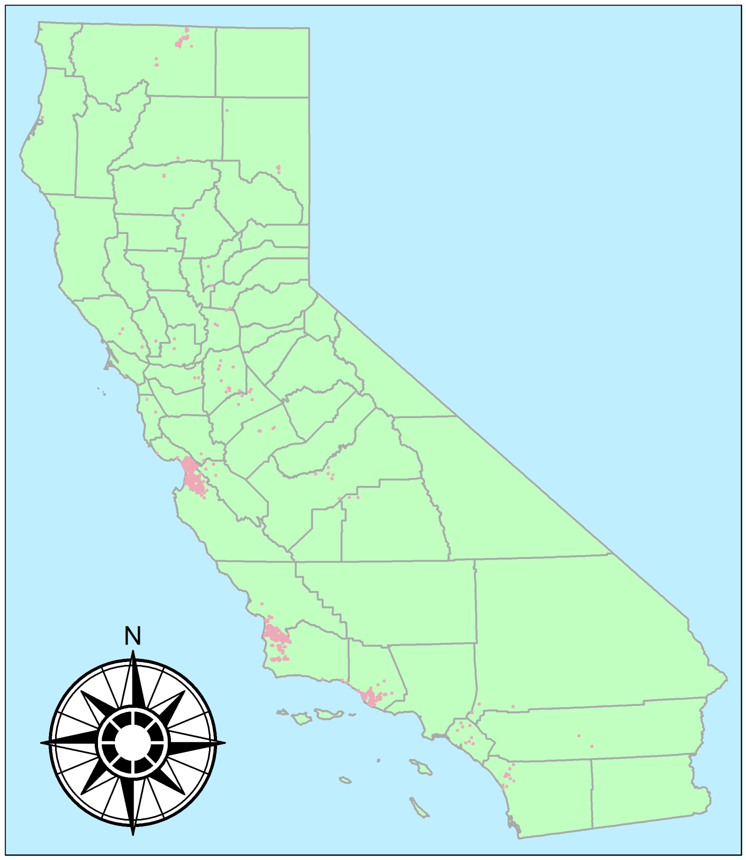


Figure 19: California Strawberry Production, 2022

strawberry was harvested on about 42,000 acres, primarily in counties along the Central Coast. These include Monterey, Santa Barbara, Santa Cruz, San Benito, San Luis Obispo, and Santa Clara counties, accounting for 80.4% statewide by tons produced from 2020–2022 (Figure 20). The Southern Coast, which includes Ventura and San Diego counties, accounts for the remaining 19.4% of statewide production, with only 0.2% produced outside of these two regions. This small share is primarily nursery production in the northern part of the state and small-holder u-pick production in the central valley and other inland areas.

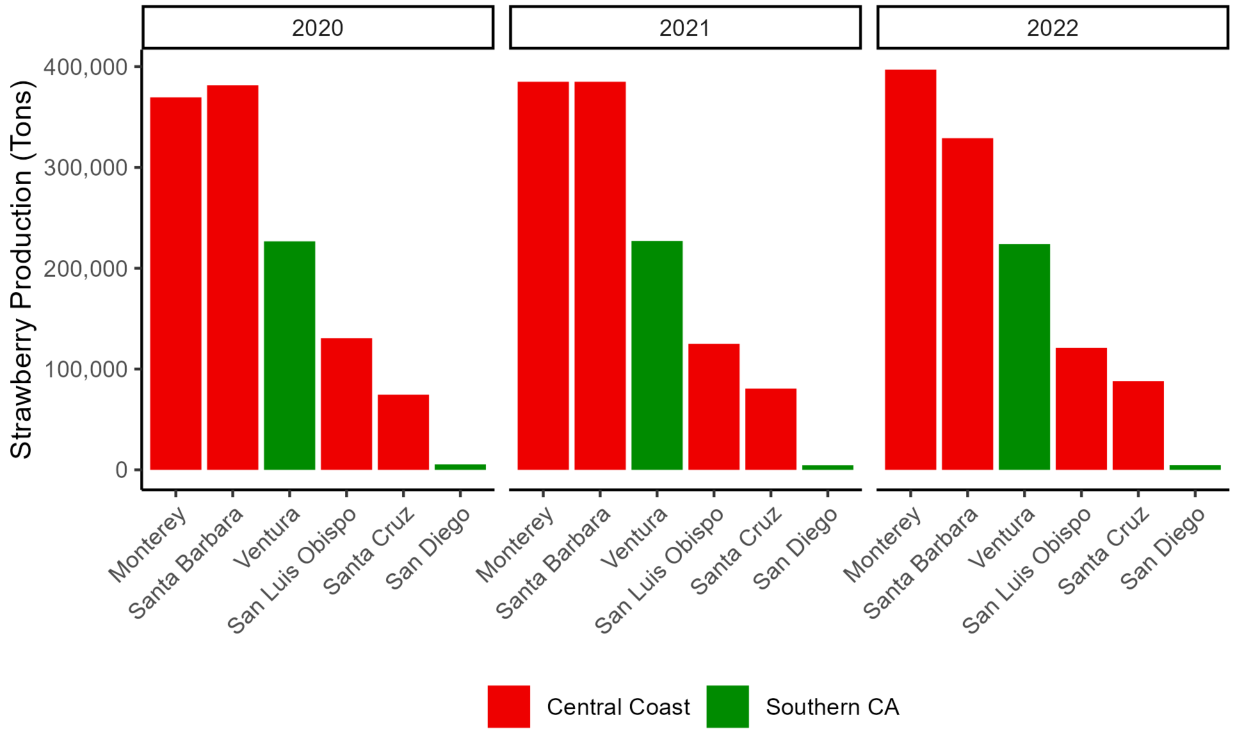
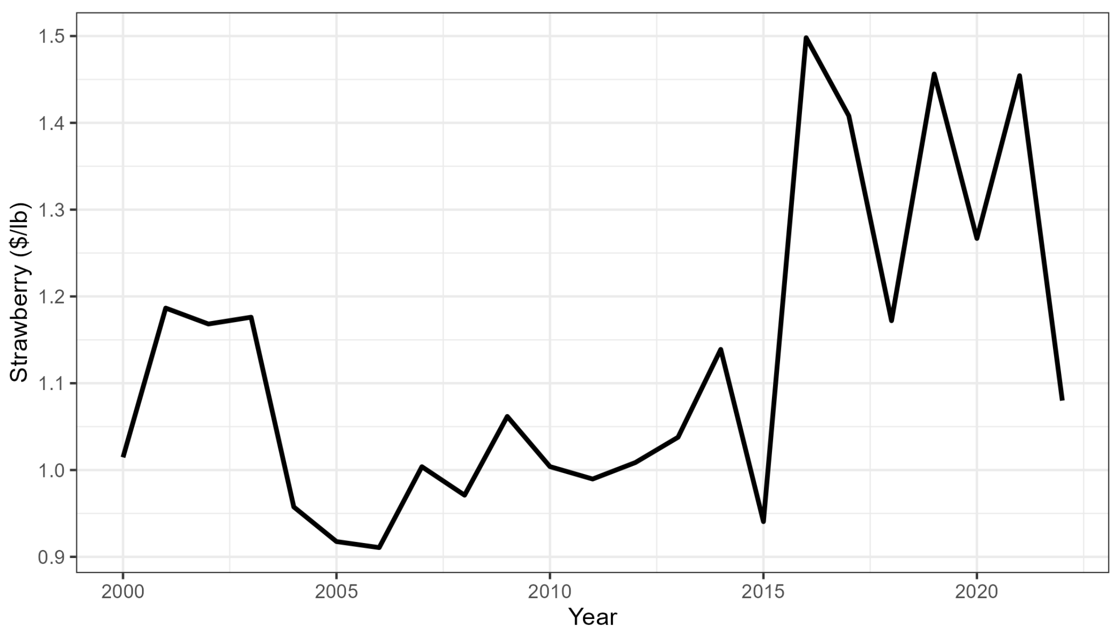


Figure 20: California Strawberry-producing counties, 2020–2022



Note: Prices are in real dollars (2022) using the Producer Price Index (PPI) for commodities (U.S. BLS, 2022)

Figure 21: Strawberry Price: 2000–2022

Since 2000, the per-pound price has fluctuated between $0.91/lb in 2006 and $1.50/lb in 2016. Figure 21 graphs the price per pound for strawberry from 2000–2022.

IPM Overview

Two pyrethroid AIs, bifenthrin and fenpropathrin, are registered to control a broad range of arthropod (includes both insects and mites) pests in California strawberries. The pyrethroids are virtually always applied by ground. They have relatively short re-entry and pre-harvest intervals that make them well-suited for use on strawberries. Their broad-spectrum activity can suppress beneficial insects in strawberries, lead to secondary pest resurgence and insecticide resistance development of non-target pest arthropods incidentally killed by an application for a target pest. Pyrethroids were first registered on strawberries in the early 1990s and became widely used because of their outstanding efficacy against hard to control insects such as lygus bug which is a key strawberry pest.

Arthropod pests associated with pyrethroid labels for California strawberries include aphids, Lepidoptera larvae (including cutworms, BAW, corn earworm, and several species of leafrollers), lygus bugs, mites (including spider mites and cyclamen mite), root weevils and grubs, vinegar flies (including spotted wing drosophila), and whiteflies. The importance of these insects may vary by region and year. As will be discussed further, the majority of pyrethroid applications target lygus bugs, but pyrethroid sprays used for lygus bug control also provide incidental (and often very effective) control of the other insects that are not the primary target of the application. This likely decreases the need for treatment for the pests incidentally controlled, but its effect is difficult to quantify.

Furthermore, California's strawberry growing regions follow two different seasonal planting systems, with 'summer planting' characteristic of Southern California and 'fall planting' characteristic of the Central Coast. This affects what time of year pest populations become damaging and thus when insecticide use occurs most heavily.

Target Pests

Lygus Bugs

Lygus bug is the greatest driver of insecticide use in strawberries, and *Lygus hesperus* is by far the most common species found in California where it is widely considered to be the most important insect pest of fresh market production. Lygus bug adults and nymphs damage fruit by feeding on developing fruit results in distortion of the fruit that is referred to as 'catfacing'. Damaged fruit cannot be marketed as fresh fruit. If untreated, damage will commonly exceed 35% from in a typical strawberry field. Lygus bug is present at damaging levels every year in all growing districts except Southern California.

Bifenthrin and fenpropathrin have been the primary insecticides used for lygus bug control for the last 25 years. The organophosphates malathion and naled have also been used historically, though are no longer considered effective due to resistance. The vast majority of pyrethroid applications target lygus bugs in both the Central Coast and Southern CA regions, especially those earlier in the year. These applications provide incidental control of spotted wing drosophila, Lepidoptera larvae, whiteflies and aphids, so insecticide treatments that might otherwise target one or more of these insects may be avoided as a result. Concern for pyrethroid resistance in lygus populations has increased in the last 15 years and neither registered pyrethroid is nearly as effective in most production areas as when they were first registered. The level of pyrethroid resistance increases through the season, leading to the use of tank mixes of pyrethroids and chemicals with different modes of action in the latter half of the season. For example, acetamiprid is not very effective as a stand-alone product, but it is a common tank mix partner with a pyrethroid, especially bifenthrin. Alternative insecticides that can be used for lygus control include novaluron, flonicamid, and flupyradifurone.

Novaluron is fairly effective for control of lygus bug nymphs and flonicamid is fairly effective at reducing lygus bug feeding, but the efficacy of both of these chemicals is reduced when lygus bug populations become greater as the harvest season progresses. Both chemicals are already used as primary controls in addition to pyrethroids and other products in the first half of the season. In general, two applications of novaluron are applied in spring in the Central Coast region with each application being relatively equivalent in efficacy to an application of a pyrethroid at this timing. Two applications of flonicamid are required to achieve the same level of control as a pyrethroid or as a pyrethroid that is applied as a tank mix with flonicamid or another chemical such as novaluron. Flupyradifurone is also considered moderately effective against lygus, with two applications of flupyradifurone being required to achieve the same level of control as a pyrethroid applied in a tank mix with flupyradifurone or another chemical.

Many strawberry growers in the Central Coast region have incorporated use of vacuum machines to suppress lygus bug populations where populations have become resistant to the primary insecticides used for their control. In these cases, weekly or twice-weekly vacuuming is usually used in combination with whatever insecticides including pyrethroids are available for their control to reduce the total amount of catfacing. It is possible that the number of pyrethroid applications has been reduced in fields using vacuum machines, but it is not considered a stand-alone control, so insecticides are still used in fields that are vacuumed. Vacuums have been shown to reduce the number of lygus bug adults by 75% and nymphs by about 9 to 50% each time a field is vacuumed, but the remaining lygus will continue to develop and reproduce necessitating continued vacuuming and potentially spraying for the remainder of the season when lygus are still present and reproductive. Furthermore, vacuum equipment can be costly and there are not enough machines available for vacuuming to be conducted across the majority of strawberry fields. Data on the costs and incidence of vacuuming in California strawberry production are not widely available and are thus not included in this report.

The unavailability of pyrethroids would likely lead to significant yield losses from lygus across strawberry producing regions, even with some alternative insecticides and vacuuming available.

Spotted wing drosophila and other vinegar flies

The first record of spotted wing drosophila (*Drosophila suzukii*) in North America was from strawberries in the Watsonville area in 2008. It is believed that they were present in strawberry fields or on other host crops in the vicinity but were not considered an economic problem until perhaps 2016 or 2017 when some growers reported outbreaks. Unlike other endemic vinegar flies that tend to feed on over-ripe fruit and therefore only have economic significance for strawberries intended for freezing or processing, spotted wing drosophila oviposit in and develop in solid fruit that are picked for the fresh market. Unmanaged populations can result in almost 100% fruit infestation. Pyrethroid resistance was reported in the Central Coast in 2017 and has increased each year. Spotted wing drosophila (SWD) populations are more susceptible early in the season, but tolerance to pyrethroids increase as each season progresses and SWD become more numerous. The greatest SWD densities and infestations occur in May and June in Southern CA, and increase from July into the fall in the Central Coast. While populations are considered to be resistant to pyrethroids, they still kill over 50% at label rates so they remain a viable option since resistant problems have also been identified with alternative chemicals as well. Bifenthrin is more widely used than fenpropathrin. As mentioned previously, these pyrethroid applications also provide control of lygus bugs as well.

Alternatives to the pyrethroids for SWD control include the spinosyns spinetoram and spinosad, malathion, and cyantraniliprole. As is the case for the pyrethroids, resistance has been identified for the spinosyns and malathion. Spinetoram and malathion have 3 day PHIs which somewhat limits the flexibility for their use relative to bifenthrin which has a 0 day PHI. Cyantraniliprole is used for SWD control by a segment of growers as well. Pyrethrum is used as a rotation for spinosad by organic growers primarily to allow a repeated application of spinosad. Pyrethrum has been shown to have little efficacy against SWD. Good field sanitation (removing damaged and older fruit) is considered an alternative to insecticides for reducing SWD populations since this practice reduces the ability of SWD and other vinegar flies to complete their life cycles. Labor cost and availability is a constraint to use of this practice.

Thrips

Strawberry fruit bronzing and flower bud abortion are attributed to thrips, primarily western flower thrips (*Frankliniella occidentalis*), although there are other causes for these symptoms including higher temperatures, UV light, and sulfur phytotoxicity (for fruit bronzing) and cyclamen mite (for flower abortion). They are primarily considered a pest in the Central Coast from May – July, and are occasionally found after flowering begins in the fall in Southern CA.

Though pyrethroids are used as a control for thrips by a number of strawberry growers, they are not labeled for this pest and their efficacy is questionable. Thrips sprays represent a minor use for pyrethroids, as spinetoram and spinosad are the most effective chemicals registered on strawberries for thrips control; they are primary used for this purpose in June and July in the Central Coast and from September through November in Southern CA.

Aphids

Several aphids affect strawberries, and the most important of these occur early in the fruiting season and can become problematic in all production districts. These include the green peach aphid (*Myzus persicae*), the strawberry aphid (*Chaetosiphon fragaefolii*), and the melon aphid (*Aphis gossypii*). The most common type of damage associated with aphid feeding is contamination of the fruit with the honeydew that they produce and the associated growth of sooty mold fungi on the honeydew. In addition, when aphids molt, their caste skins stick to the fruit. Fruit contamination with honeydew, sooty mold and insect skins renders the fruit unmarketable for fresh market greatly reducing the value of the fruit. Aphids can also transmit viruses that significantly reduce fruit yield, among them *strawberry mottle virus*, *strawberry crinkle virus*, and *strawberry mild yellow edge virus*. Aphid transmitted viruses are not a serious problem in annual production plantings when the strawberry transplants are certified as virus-free, but they can become problematic in strawberries that are grown for more than one year. Aphid control to prevent transmission of viruses is a major concern for California strawberry nursery production since these nurseries undergo a state certification process before their transplants can be sold. All strawberry nurseries routinely treat for aphids to meet certification standards, however this report does not cover treatments in nurseries.

Some pyrethroid applications are made early in the fruiting season in all districts during March - April when aphids first appear in all production areas, but foliar insecticides are not needed in most fields and in every year. They are most often used in the absence of suppression achieved through imidacloprid applied by chemigation or foliar applications of thiamethoxam before initiation of flowering. When aphids are present after flowering and a treatment is needed, a number of products can be substituted for pyrethroid treatments including flupyradifurone, naled, flonicamid, and acetamiprid. When populations are modest or for organic production, azadirachtin, oils and insecticidal soap are also effective, however oils are a concern for growers due to their potential for phytotoxicity.

Whiteflies

The most important whitefly pest of California strawberries is the greenhouse whitefly (*Trialeurodes vaporariorum*) which occurs in all growing regions. Other whiteflies present include in strawberry fields include the iris whitefly (*Aleyrodes spiroeoides*) and the strawberry whitefly (*Trialeurodes packardi*). Whiteflies reduce yield directly through their feeding on leaf tissue that stunts plant growth and reduces fruit quality. Like aphids, they produce sticky honeydew on the fruit surface that causes growth of sooty mold fungi that renders the fruit unsuitable for the fresh market, and can transmit plant viruses including *strawberry pallidoses associated virus* and *beet pseudo yellows virus* that can result in rapid plant decline when they are present in tandem or with other plant viruses. Serious greenhouse whitefly outbreaks often accompanied by virus transmission to strawberries have occurred on several occasions in the last decade, resulting in significant crop losses for growers across regions.

Pyrethroids are seldom used for whitefly control, although a tank mix of fenpropathrin and malathion can be applied after whitefly populations begin to build during the harvest season. Where there is a high probability of their occurrence, whiteflies are typically controlled with imidacloprid applied by chemigation after transplanting and before flowering. This has been shown to be the most effective approach for controlling greenhouse whiteflies rather than applying chemicals after whiteflies begin to appear in spring. While not considered in this analysis, the fenpropathrin applications applied from January – March in Southern CA and extending into April in the Central Coast may target whiteflies, especially in fields where imidacloprid was not applied prior to flowering.

Lepidopteran Larvae

A number of Lepidopteran larvae attack strawberries, feeding both on foliage and fruit. These include the BAW (*Spodoptera exigua)*, corn earworm (*Helicoverpa zea)*, black cutworm (*Agrotis ipsilon)*, roughskinned cutworm (*Athetis mindara)*, variegated cutworm (*Peridroma saucia*), and the light brown apple moth (*Epiphyas postvittana*). Bifenthrin and fenpropathrin are registered and effective for controlling Lepidoptera larvae, however Lepidoptera larvae are seldom targets for pyrethroid applications in California strawberries, primarily because growers are at high risk of lygus bug damage for as much as 6 months primarily from May – October. Since treatments applied to control Lepidoptera larvae mainly occur from in spring and early summer and the number of pyrethroid spray that can be used during the season is limited by total AI of each product that can be applied, growers often choose to save the ability to use bifenthrin and fenpropathrin later in the season when lygus typically become problematic. This decision is made possible because there are several alternative chemicals available for control of Lepidoptera larvae, including methoxyfenozide, chlorantraniliprole, and cyantraniliprole. However, as pyrethroids are not generally used for control of Lepidopteran pests, these chemicals are not considered as alternatives.

Root Wevils and Grubs

Several species of root beetles are considered pests of strawberries in other US growing areas. Those species that are reported to occur in California include the black vine weevil (*Otiorhynchus sulcatus*), the cribrate weevil (*Otiorhynchus cribricollis*), Fuller rose weevil (*Pantomorus cervinus*), and two species of scarab beetles (*Hoplia dispar* and *H. callipyge*). These are rarely of concern for California strawberry production and only occasionally occur in nonfumigated fields that follow a host crop for the beetles or in second-year strawberry fields. Unless the current California production system that incorporates annual plantings and preplant soil fumigation changes dramatically, root weevils and grubs are not likely to become a significant problem.

Root weevils appear on bifenthrin and fenpropathrin labels and could be used for their control. Diazinon applied by chemigation would be more effective in controlling these beetles, however the 5 day PHI associated with diazinon would limit its use during the harvest season.

Garden Symphylan

The garden symphylan (*Scutigerella immaculata*), is not found in fumigated strawberry fields but may be present in nonfumigated fields, especially those planted on sandy soils with high organic matter such as where the planting follows a cover crop or other symphylan hosts. Symphylans feed on the developing root system and can severely weaken or kill the young strawberry plants. They are usually detected when stunting is observed shortly after the plants start to develop, and fields must be treated if symphylans are found. Treatment timing is usually before flowering from September -November in the Southern CA and November – March in the Central Coast region. Fenpropathrin is registered for symphylan control. The alternative chemical is diazinon which has somewhat better efficacy than fenpropathrin but also a 5 day PHI.

Mites

Spider mites including the two-spotted spider mite (*Tetranychus urticae*), and the Lewis mite (*Eotetranychus lewisi*), are pests in all strawberry growing areas and require treatment every year. Spider mite feeding reduces the number of flower buds and leaf photosynthetic activity resulting in reduced fruit yield. Many researchers and growers consider spider mites second to lygus bugs as a primary arthropod pest of strawberries. Both bifenthrin and fenpropathrin are also registered as acaricides meaning that they kill mites, and they reduce mite populations when they are applied for insect pests. Though pyrethroids are not applied specifically to control spider mites, their use can also kill spider mite predators, leading to the mites resurgence after chemical residues are no longer sufficient to kill them, and ultimately the need for additional applications of acaricides.

In addition to acaricides, about 80% of strawberry growers release predatory mites such as *Phytoseiulus persimilis* for spider mite and *Neoseiulus californicus*, and other species for Lewis mite in spring to suppress spider mite populations. Acaricide applications targeting spider mites usually begin by May in the Central Coast and earlier in Southern CA after insecticides (including pyrethroids) begin to be applied for control of other target pests.

Pyrethroid Use: 2020–2022

Monthly pyrethroid use in strawberries are presented in Figure 22. Peak pyrethroid use varies by region based on the seasonal planting system most prominent in that region; fall planting is more common in the Central Coast and summer planting is more common in Southern CA. Virtually all conventionally-managed fields receive at least one application of a pyrethroid and many receive more than one application each year, with bifenthrin more widely used than fenpropathrin.

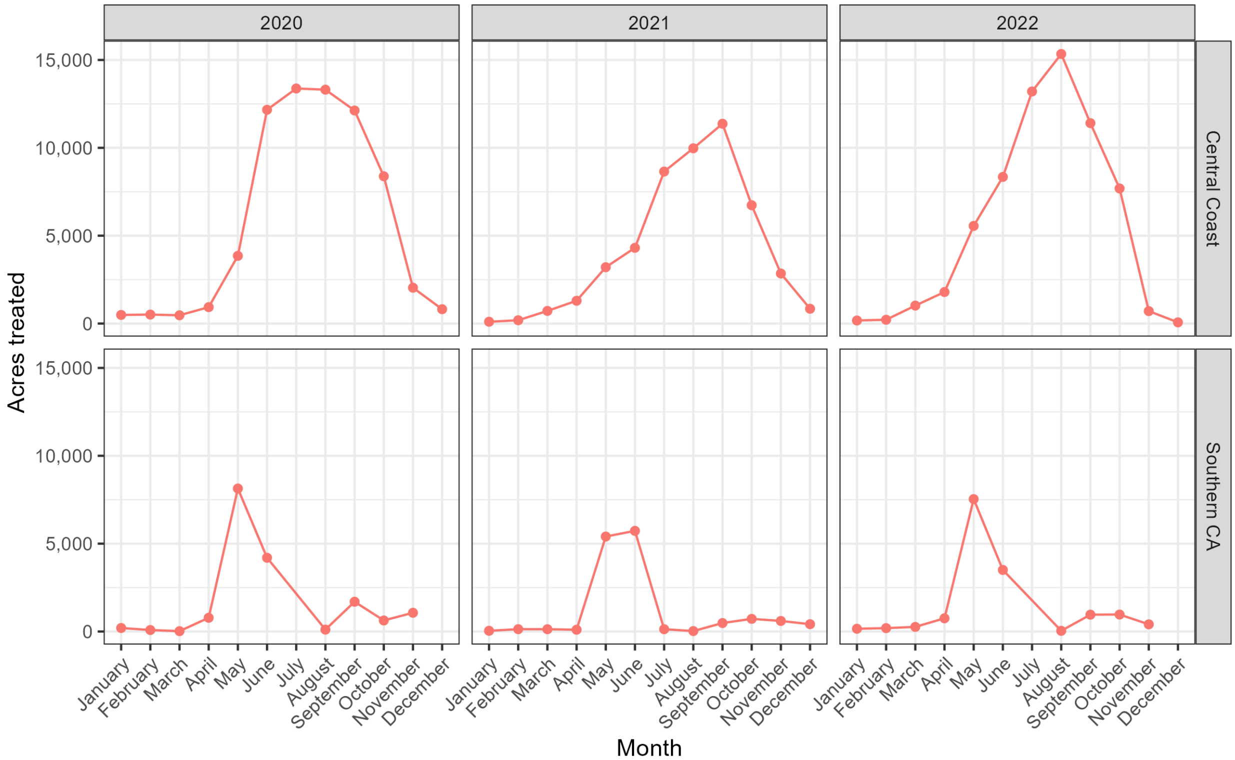


Figure 22: Monthly Use of Pyrethroids by Region: Strawberry, 2020–2022

Table 40 reports pounds applied, acres treated, and use rates for pyrethroids and alternative AIs in strawberry. Novaluron, flonicamid, and azadirachtin were the AIs applied to the largest number of acres. Bifenthrin was the pyrethroid applied on the largest number of acres and the fourth-most applied of all AIs.

Table 40: Annual Use of Pyrethroids and Alternative Active Ingredients: Strawberry, 2020–2022

	Lbs. Applied				Acres Treated				Use Rate (lb/ac)
Active Ingredient	2020	2021	2022	Total	2020	2021	2022	Total	
acetamiprid	3,742	3,584	4,985	12,311	32,155	28,241	40,047	100,443	0.12
azadirachtin	1,665	1,906	2,151	5,722	49,549	55,809	66,307	171,665	0.03
bifenthrin*	7,093	5,490	6,895	19,478	60,624	46,228	57,175	164,027	0.12
cyantraniliprole	1,361	1,250	993	3,604	13,305	11,630	9,406	34,341	0.1
fenpropathrin*	7,271	5,363	7,214	19,848	25,088	18,035	23,246	66,369	0.3
flonicamid	5,162	4,818	5,860	15,840	59,518	55,410	67,382	182,310	0.09
flupyradifurone	5,195	5,300	7,367	17,862	31,893	30,566	41,070	103,529	0.17
imidacloprid	5,104	4,578	4,819	14,501	11,495	10,476	11,317	33,288	0.44
malathion	64,250	44,208	66,444	174,902	32,129	22,152	33,418	87,699	1.99
naled	15,342	14,966	26,151	56,459	15,285	14,883	26,033	56,201	1
novaluron	5,748	4,870	6,091	16,709	82,369	64,230	80,024	226,623	0.07
pyrethrins	559	367	624	1,550	11,133	8,228	13,771	33,132	0.05
spinetoram	3,185	2,500	2,586	8,271	43,162	34,058	35,041	112,261	0.07
spinosad	1,042	1,356	1,311	3,709	11,600	14,486	13,323	39,409	0.09
thiamethoxam	1,093	864	1,238	3,195	17,757	14,260	19,991	52,008	0.06

*Target Pyrethroids

Economic Analysis

This section presents the expected change in costs to strawberry if pyrethroid insecticides were to become unavailable. Both pest management costs and gross revenues may be affected.

Pest management costs.

Table 41 presents representative products for each active ingredient used on strawberry in 2020–2022 and their costs per acre. The material cost per acre is the product of the average use rate (lb/ac) over this period and the price per pound. The material cost per acre ranges from $15.14 to $96.41. Growers consider other factors in addition to price per acre when choosing insecticides, as discussed above.

For pyrethroids that are tank mixed with flonicamid or flupyradifurone, two applications of these two AIs are needed to replace one application of pyrethroid. Where pyrethroids are tank mixed with both flonicamid and flupyradifurone, we assume two applications of flupyradifurone for replacement as a conservative estimate given its higher cost. It is possible in some fields that this increase in the number of applications would exceed label restrictions on total annual uses of these products, which is not accounted for in our analysis. In addition, reduced yields from a lack of alternatives for lygus control lead to lower revenues.

Table 41: Representative Product Cost per Acre: Strawberry, 2020–2022

Active ingredient	**Representative product**	**Cost per acre ($)**
acetamiprid	Assail 70wp Insecticide	15.14
azadirachtin	Aza-Direct	96.41
bifenthrin*	Brigade Wsb Insecticide/Miticide	46.31
cyantraniliprole	Exirel Insect Control	66.93
fenpropathrin*	Danitol 2.4 Ec Spray	24.97
flonicamid	Beleaf 50 Sg Insecticide	33.25
flupyradifurone	Sivanto Prime	51.95
imidacloprid	Admire Pro Systemic Protectant	38.59
malathion	Malathion 8 Aquamul	15.14
naled	Dibrom 8 Emulsive	17.63
novaluron	Rimon 0.83 Ec Insecticide	34.62
pyrethrins	Pyganic Crop Protection Ec 5.0 Ii	70.02
spinetoram	Radiant Sc	94.40
spinosad	Success	45.95
thiamethoxam	Actara	26.22

*Target Pyrethroids

Table 42 shows the average acreage shares for each alternative AI used on strawberry, with and without pyrethroids being available. Averaged over the three-year period 2020–2022, pyrethroids represented 15.7% of the total applications to strawberry acres treated with pyrethroids or an alternative AI. Total acres treated with insecticides do not correspond to physically unique acres because some growers may have used multiple AIs on the same field. The three most common alternative AIs were novaluron, flonicamid, and azadirachtin, together accounting for 39.7% of total strawberry acres treated with pyrethroid insecticides and the alternatives, which is projected to increase to 47.1% of acres treated without pyrethroids.

Table 42: Average Annual Acreage Shares of Alternative Insecticides with and without Pyrethroids: Strawberry, 2020–2022

Active ingredient	Pyrethroids available (%)	Pyrethroids unavailable (%)
acetamiprid	6.9	8.1
azadirachtin	11.7	13.9
cyantraniliprole	2.3	2.8
flonicamid	12.5	14.8
flupyradifurone	7.1	8.4
imidacloprid	2.3	2.7
malathion	6.0	7.1
naled	3.8	4.6
novaluron	15.5	18.4
pyrethrins	2.3	2.7
spinetoram	7.7	9.1
spinosad	2.7	3.2
thiamethoxam	3.6	4.2
Total	**84.3**	**100.0**

Note: Three-year average from 2020–2022.

Table 43 shows the average per acre costs for target pyrethroids as well as the cost of the composite alternative. For strawberry, switching to the alternative would increase material costs. Bifenthrin users will incur a per acre cost increase of $1.83, or 4% and fenpropathrin users will incur a per acre cost increase of $23.17 (93%).

Table 43: Costs per Acre for Target Pyrethroids and the Composite Alternative: Strawberry, 2020–2022

Active ingredient	Cost per acre ($)	Cost increase for switching to composite alternative (%)
bifenthrin	46.31	4
fenpropathrin	24.97	93
composite alternative	48.14	-

Table 44 reports the expected change in costs due to the unavailability of pyrethroids. Insecticide costs for management of the target pests in strawberry are estimated to increase approximately by one third. The percent change in costs ranges from 30.6% in 2022 to 31.4% in 2020. Correspondingly, the total change in costs ranges from $0.99 million in 2022 to $1.08 million in 2020. The pyrethroids bifenthrin and fenpropathrin are similarly priced with alternative ingredients, so the increase in treatment costs for strawberry growers if pyrethroids were unavailable is less than for other focal crops.

Table 44: Change in Treatment Costs due to the Unavailability of Pyrethroids: Strawberry, 2020–2022

Year	Pyrethroids available ($)	Pyrethroids unavailable ($)	Change in cost ($)	Change in cost (%)
2020	3,434,109	4,513,994	1,079,886	31.4
2021	2,594,229	3,402,323	808,094	31.1
2022	3,225,234	4,212,132	986,898	30.6

Change in gross revenues. Without pyrethroids available, there is a high likelihood of yield losses across strawberry production. In the absence of management, lygus can damage up to 35% of strawberries in a field (Zalom, 2008). While alternative chemical products are somewhat effective in controlling lygus, they are unlikely to provide equivalent control despite increased numbers of applications of some materials to replace pyrethroid tank mixes. Additionally, vacuuming for lygus is most effective in combination with pyrethroid applications and provides only temporary, limited control on its own. To account for this, we projected a 15% yield loss for strawberries across all regions, resulting from incomplete lygus control due to less effective chemical alternatives and incomplete availability of vacuuming across fields. A caveat is that this projected yield loss serves only as our estimate, as the cost, availability, efficacy, and adoption rates of vacuuming and the frequency and intensity of lygus outbreaks in strawberry are difficult to quantify.

The change in toral revenue depends on how the price of strawberry changes in response to a change in quantity. The own-price elasticity of demand represents the relationship between the change in quantity and the change in price. If an elasticity is smaller in magnitude than -1 (inelastic), an increase in price is associated with a less than proportionate increase in the quantity demanded, and total revenue increases. If it is larger than -1 in magnitude (elastic), then the decrease in the quantity demanded is larger than proportionate than the change in price, and total revenue falls. If the own-price elasticity of demand is -1, then gross revenue remains the same. The largest gross revenue decline occurs when demand is perfectly elastic (i.e., Elasticity = $-\infty$). In this case there is no increase in price when the quantity produced declines. Perfectly elastic demand corresponds to a case where California production is a small share of total market production and thus had little influence on the market-clearing price. However, California accounted for 84.0% of national production in 2022 (CDFA, 2023a). Given the large share of strawberry on the national market, reductions in California's supply would likely increase the market-clearing price. We apply three own-price elasticity estimates for California strawberry: two imperfect elasticities, -1 (lower bound) and -1.26 (upper bound), and one perfect (infinite) elasticity. The imperfectly elastic estimates are from Sobekova et al. (2013) and Ferrier et al. (2023).

If pyrethroids were available, California strawberry farmers would receive the price and yield reported in the 2022 California Agricultural Statistics (CDFA 2023). Table 45 reports the outcomes under the three own-price demand elasticities; the perfectly elastic scenario (no price change, Column 4, Table 45) and two scenarios with imperfect elasticities (Columns 5 and 6, Table 45). The lower- and upper-bound imperfect price elasticity scenario prices are 7.7% and 6.1% higher than those in the perfectly elastic scenario, respectively.

Table 45: Annual Yield and Price for California Strawberry

Yield (tons)		**Price ($/ton)**			
Pyrethroids available	**Pyrethroids unavailable**	**Pyrethroids available**	**Pyrethroids unavailable**		
			Perfectly elastic Elasticity =-∞	**Imperfect:lower bound Elasticity=-1**	**Imperfect:upper bound Elasticity=-1.26**
29.50	25.08	2,160.00	2,160.00	2325.89	2291.66

Table 46: Change in Gross Revenue due to 15% Yield Loss on Acreage Treated with Pyrethroids from the Unavailability of Pyrethroids, 2020– 2022

Year	**Gross revenue with pyrethroids available ($)**	**Gross revenue with pyrethroids unavailable ($)**	**Change in gross revenue ($)**	**Change in gross revenue (%)**
		Perfectly elastic: Elasticity = -∞		
2020	1,490,209,781	1,266,678,314	223,531,467	15.0
2021	1,407,479,857	1,196,357,879	211,121,979	15.0
2022	1,722,457,375	1,464,088,768	258,368,606	15.0
		Imperfectly elastic, lower bound: Elasticity = -1		
2020	1,490,209,781	1,490,209,781	0	0.0
2021	1,407,479,857	1,407,479,857	0	0.0
2022	1,722,457,375	1,722,457,375	0	0.0
		Imperfectly elastic, upper bound: Elasticity = -1.26		
2020	1,490,209,781	1,343,885,168	146,324,614	9.8
2021	1,407,479,857	1,269,278,546	138,201,311	9.8
2022	1,722,457,375	1,553,328,228	169,129,147	9.8

Note: Reported gross revenue reflects harvested acreage treated with pyrethroids during the 2020–2022 period.

Gross revenue is the product of output (yield × acreage) and the realized price. Table 46 reports the estimated change in gross revenues for California strawberry if pyrethroids were unavailable. Under the expected 15% yield loss, the magnitude of the change in gross revenue change depends on the elasticity of demand: under the worst-case scenario (Elasticity = -∞), gross revenue losses range from \$211.1 million to \$258.4 million (15%); under the lower bound scenario, prices increase most significantly and gross revenues do not change (0.0%); and under the upper bound scenario, from \$138.2 million to \$169.1 million (9.8%).

Tomato

Tomatoes in California are grown for two markets: fresh and processed. California is the largest producer of processing tomato and the second largest producer of fresh tomato in the U.S., behind only Florida. There were 17,800 acres of fresh tomato and 225,000 acres of processing tomato in 2022, with production worth $293 million and $1.17 billion, respectively (CDFA, 2023a).

Fresh tomato production occurs in many areas of California but is concentrated in the Central Valley and Central Coast with the greatest production value coming from Merced (11.6%), San Joaquin (10.1%), San Benito (8.9%) counties in 2022. Until recently, southern California counties were also important for fresh market tomato production, but the value of production in this area has declined substantially largely due to urbanization and competition from imported fruit from Mexico.

California produces virtually all of the processing tomato in the United States, and most of the production is concentrated in the Central Valley. Production value in Fresno County is the greatest of any county (22.1%). The next largest processing tomato producing counties were Yolo (16.5% of production value), Kings (15.9%), Merced (10.5%), and Sutter (8.1%). The concentration of processing tomato production has remained relatively stable for the last two decades and is due to the processing/cannery infrastructure that is also located in the Central Valley.

Fresh market tomato is primarily grown in 'bush' type production on large fields as a row crop. Bush varieties are determinate and picked once (or at most a few times) during the season. 'Pole' tomato is less common and tend to be produced on a smaller scale that is more labor intensive. Pole tomato varieties are indeterminate meaning that they continue to produce fruit that can be harvested over a long period of time during the production season. The length of the production season and proximity of nearby fields has a significant impact on the type and abundance of pests because insect populations tend to increase in abundance throughout the production season. Because fresh tomato is typically used whole by consumers, appearance is important, so growers strive to produce unblemished fruit. Some fresh tomato is grown in greenhouses that require a different pest management program and have a somewhat different arthropod pest complex, however this accounts for less than two percent of California fresh tomato production by yield and is not addressed in this report.

Processing tomato is all grown in 'bush' type production, with determinate varieties grown for a single mechanical harvest. Canneries process the tomatoes into juice, paste, diced, and whole pack products. Growers enter contracts with canners, who dictate specific conditions for varieties, delivery volume and timing, and inspection for pest damage and pesticide maximum residue levels (MRLs). Adherence to these conditions is crucial and is often tied to contract renewal, so maintaining consistent deliveries, limiting 'worm' damage and 'mold' below specified limits, and ensuring insecticide residues are in compliance with both US regulations and importing nations requirements are important considerations in growers' pest management decision-making.

The significance of a particular pest species can vary somewhat by region of the state, but many of the pests occur in all production areas. This report refers to two production regions for fresh market production (the Central Valley and the Coastal Valleys) and two for processed tomato (the San Joaquin Valley and the Sacramento Valley) when discussing pest pressure. Limited processing tomato production also occurs in some coastal valley counties, but this production is shipped to Central Valley canneries for processing and pest control practices are like those of Central Valley counties.

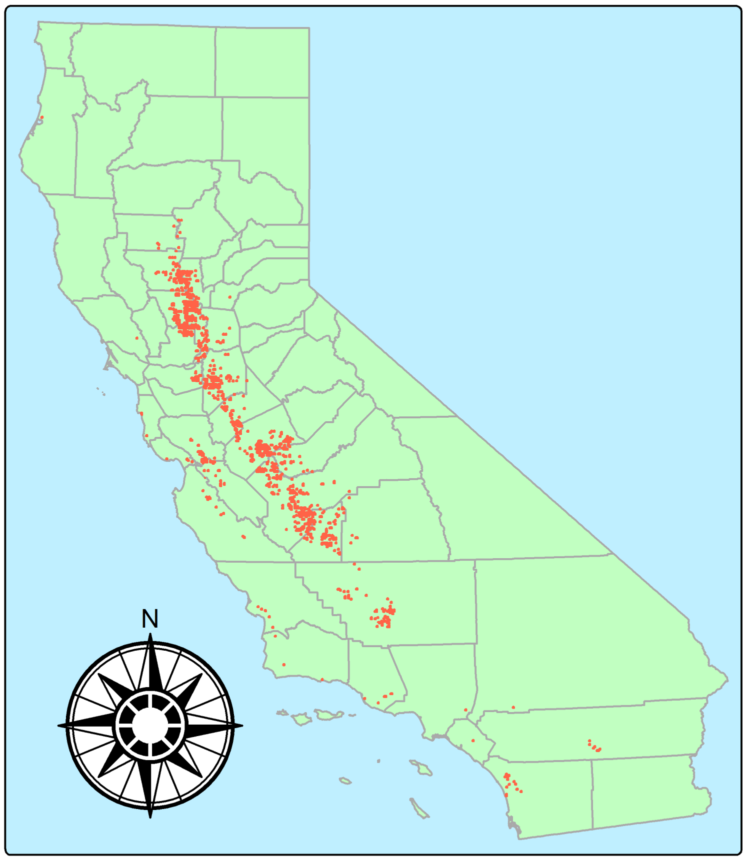


Figure 23: California Fresh and Processing Tomato Production: 2022

IPM Overview

Seven pyrethroid AIs, cyfluthrin, bifenthrin, esfenvalerate, fenpropathrin, lambda cyhalothrin, permethrin, and zeta-cypermethrin, are registered to control a broad range of arthropods pests in California tomatoes. [1] Of these permethrin, one of the first pyrethroids registered,

[1]Beta-cyfluthrin is excluded from this analysis due to its minimal usage.

is seldom used because growers and PCAs consider it to be the least effective, so references made to 'all pyrethroids' throughout this report are not inclusive of permethrin.

Arthropod pests associated with pyrethroid labels for California tomato are diverse, though the importance of tomato arthropod pests may vary somewhat by region and year. Of these pests, the most important are those that damage fruit directly such as many of the Lepidopteran larvae, stink bugs, and to some extent lygus bugs and false chinch bugs; that transmit viruses including whiteflies, thrips, leafhoppers and some aphids; or that reduce stands at the time of plant establishment such as cutworms, flea beetles and garden symphylans.

They can be applied both by ground or air. Method of application often depends on the size of a field and the biology of the insect being targeted. It is important to note that pyrethroids may also be applied as tank mixes with other classes of insecticides to enhance their efficacy against insects that are particularly difficult to control such as stink bugs or to control multiple target pests at once. Pyrethroids kill insects more quickly than most alternative insecticides, which can be particularly important when there is an outbreak of a fruit feeding pest that can continue to damage fruit before they are killed. Related to this, pyrethroids are more effective in controlling later instars of immature of pests than are most alternative products that tend to be more effective against earlier (and smaller) instars.

Target Pests

Lepidopteran Larvae

Many Lepidopteran larvae attack tomatoes, feeding both on foliage and fruit. Those species feeding on fruit are typically of greater concern since the fruit fed upon are not acceptable for fresh market and the entire truck load of processing fruit will be rejected following inspection by state graders if more than 4 percent of the load have 'worms' present or evidence of insect feeding. All tomato loads are inspected at state grading stations before they proceed to canneries for processing. The most important of the fruit feeding species are armyworms (BAW*Spodoptera exigua* and the western yellow-striped armyworm *Spodoptera praefica*), the tomato fruitworm *Helicoverpa zea*, cutworms (the black cutworm, *Agrotis ipsilon*, and the variegated cutworm, *Peridroma saucia*), and the tomato pinworm, *Keiferia lycopersicella*, which is primarily a problem in fresh market tomatoes on the east side of Fresno, Madera, and Tulare counties, the coastal valleys, and southern California. Hornworms (the tobacco hornworm, *Manduca sexta*, and the tomato hornworm, *Manduca quinquemaculata)* also feed on tomatoes but are primarily associated with fresh market tomato production, especially organic production and in smaller scale plantings. Preventing Lepidoptera feeding on fruit during the production season is the most important use for pyrethroids and all pyrethroids are effective in their control. Alternatives that are effective for control of Lepidopteran larvae include methoxyfenozide, chlorantraniliprole, the spinosyns spinetoram and spinosad, novaluron, emamectin benzoate, and indoxacarb. *Bacillus thuringiensis aizawai*, which is more effective against armyworms, and *Bacillus thuringiensis kurstaki* are microbial insecticides that require at least two applications to achieve equivalent control to a single pyrethroid application due to their short residual activity. They are also not as effective against later instar larvae as newly eclosed larvae. Advantages of using pyrethroids instead of the alternative insecticides is that they tend to kill the larvae more quickly and are more effective against later instar larvae that are larger and more difficult to control, so are more useful as rescue sprays. Perhaps 25% of pyrethroid sprays applied to tomatoes prior to June target Lepidopteran larvae and 20% of pyrethroid sprays applied June or later target Lepidopteran larvae.

Cutworms and BAWs can be damaging in seedling tomato fields after transplanting and can reduce the plant stand. In rare cases the entire field may require replanting. This damage typically occurs when the field is planted when a cover crop precedes seeding or transplanting or weeds have not been controlled prior to planting. Pyrethroids are effective in control but are seldom used for this purpose early season. Carbaryl bait and diazinon are also effective, and this represents a minor use of pyrethroids in tomato production.

Armyworms, hornworms, and loopers (the alfalfa looper, *Autographa californica*, and the cabbage looper *Trichoplusia ni)* feed on leaves, but this damage rarely causes significant yield loss in processing tomatoes. However, foliage feeding can be more of a concern for fresh market pole tomatoes since loss of foliage can reduce fruiting on indeterminate varieties. Pyrethroids are effective for control of these insects, but the number of sprays applied to fresh market tomatoes for this purpose is likely less than 5% of use. The same alternative insecticides used to control fruit feeding Lepidopteran larvae are effective for this purpose, and *Bacillus thuringiensis kurstaki* is particularly effective against the loopers.

Stink Bugs

Several stink bug species including consperse stink bug (*Euschistus conspersus*), redshouldered stink bug (*Thyanta custator accerra*), Say's stink bug (*Chlorochroa sayi*), Uhler's stink bug (*Chlorochroa uhleri*), and Southern green stink bug (*Nezara viridula*), attack both fresh market and processing tomatoes in the Sacramento and central and northern San Joaquin Valleys. About 25% of the total tomato acreage in these regions can be seriously affected. They are less of a concern in the coastal valleys and southern California. Stink bugs inject saliva into fruit when feeding that results in fissures below the surface of the fruit. This damage is unacceptable for marketing of fresh market fruit and processing tomatoes that are not used for sauce, paste, or juice. Yeasts and other pathogens may also be injected into the fruit because of their feeding, resulting in rejection of processing tomato loads or a reduced price due to 'mold damage' identified at state grading stations. Because stink bugs must reinvade tomato fields each year, usually in June or later, much of the damage occurs nearer field edges so fruit from only a portion of each field is damaged. However, the entire field is typically treated for stink bugs once they are present in the field.

Stink bugs are notoriously difficult insects to control with any insecticide. Pyrethroids are the primary insecticides applied for stink bug control in tomatoes, and their efficacy is increased when they are applied in a tank mix with insecticides from other classes including acetamiprid, methomyl, an organophosphate such as malathion or diazinon, novaluron, or cyantraniliprole. Many growers and PCAs consider lambda–cyhalothrin to be the most effective of the pyrethroids for stink bug control. At least 40% of the pyrethroid sprays applied June or later in the central valley target stink bugs, and the applications that are reported to have been applied as a tank mix with another insecticide are likely to have been used for stink bug control. Kaolin clay can suppress stink bug feeding on tomatoes, but its practical utility is limited because it must completely cover the fruit, which requires a very high amount of AI and repeat applications as the fruit increase in size and mature. This limits its usefulness for large scale application in fresh market tomato production, and it is not included in this analysis.

Aphids

Several aphid species affect tomatoes. The most important ones are the green peach aphid (*Myzus persicae*) and other early season aphids, and the potato aphid (*Macrosiphum euphorbiae*) that occurs later in the season. Feeding by green peach aphids can injure young plants that are stressed by water or other factors and may transmit virus diseases such as alfalfa mosaic virus when the tomato field is grown nearby a virus source. Early season aphids rarely require treatment and are controlled with neonicotinoids such as imidacloprid and thiamethoxam applied before tomato plants begin to bloom although aphids are usually not the primary target of these applications unless the field is located near a potential source of alfalfa mosaic virus. The potato aphid occurs later in the season than does green peach aphid, usually not being found before late June or when plants are well into flowering. Potato aphid injures tomato plants by distorting leaves and stems and stunting plants. High populations that occur six to eight weeks before harvest can significantly reduce yield, and populations that reduce the plant canopy closer to harvest can cause sunburn of fruit. Potato aphids are primarily of concern for fresh market and processing tomatoes in the northern San Joaquin Valley and Sacramento Valley.

All the registered pyrethroids are effective in controlling aphids, and perhaps a quarter of the use of pyrethroids applied May or earlier target control of green peach aphid and other aphids. Perhaps 20 percent of pyrethroids applied June or later target potato aphid and other aphids, but with the recognition that the application will also suppress other pests that are routinely found in tomatoes later in the season. Effective alternative insecticides to pyrethroids for aphid control include spirotetramat, pymetrozine, flonicamid, flupyradifurone, afidopyropen, dimethoate, malathion, and acetamiprid. Pyrethrins, azadirachtin, and insecticidal soap can be used to control aphids by organic farmers but are rarely used for aphid control by conventional growers due to cost, and narrow range of activity against other pests. Oils are also effective against aphids, but their application can cause phytotoxicity during periods of hot weather when temperatures exceed about 90°F.

Flea Beetles

Flea beetles, *Epitrix hirtipennis*, and other species, are a pest of seedling processing tomatoes in the San Joaquin and Sacramento Valley regions. They slow growth by causing damage to young leaves and stalks. The economic impact of this damage has declined with the transition from direct seeding to transplanting. Flea beetles occasionally become a late season pest when leaves are senescing, and they begin feeding on the fruit instead. Imidacloprid and thiamethoxam as a preplant application is effective for flea beetle control early season in direct seeded and transplanted fields. Carbaryl bait is an effective alternative for early season control. Pyrethroids are used for flea beetle control when a foliar application is needed to control flea beetles as leaves begin to senesce prior to harvest to prevent their feeding on fruit. Perhaps 5% of pyrethroids applied July or later target flea beetles. The loss of nitroguanidine-substituted neonicotinoids (NGNs), which includes imidacloprid, thiamethoxam, dinotefuran, and clothianidin, has increased the importance of pyrethroids for this purpose. Carbaryl foliar sprays are an effective alternative to pyrethroids, but they have a longer PHI (3 days) which can limit their use as a rescue spray close to harvest.

Lygus Bugs

Lygus hesperus and other species. Lygus are common in San Joaquin Valley tomato fields and to a lesser degree in Sacramento Valley fields. Adult lygus are highly mobile insects and tend to move to tomatoes after their preferred hosts, such as alfalfa and safflower, are harvested. They feed on tomato fruit, causing small surface cracks that are primarily of concern for fresh market tomatoes and diced or whole pack processing tomatoes. However, lygus bugs seldom reach treatable levels in tomatoes. In the event that lygus populations are sufficiently great as to warrant treatment, the pyrethroids lambda-cyhalothrin, zeta-cypermethrin, and fenpropathrin alone or in combination with acetamiprid provide inexpensive and effective control. Perhaps 5% of pyrethroid sprays applied June and later in the season specifically target lygus bugs. Alternative products with similar efficacy include methomyl and dimethoate. Flonicamid is slower to control lygus populations in tomatoes but is also effective.

Thrips

The primary thrips species that infests tomatoes in California is the western flower thrips (*Frankliniella occidentalis*) although onion thrips (*Thrips tabaci*) is often found on tomatoes as well, particularly on the west side of the San Joaquin Valley. Very high populations of thrips can somewhat reduce yield through flower aborting resulting from their feeding. However, the most serious damage caused by thrips is their transmission of Tomato spotted wilt virus, which can seriously reduce yield (Sevik and Arli-Sokmen, 2012). Tomato spotted wilt virus is an important concern on fresh market tomatoes, and on processing tomatoes in the San Joaquin Valley. A host plant resistance-breaking strain of Tomato spotted wilt virus, first found in 2016, has made thrips control with insecticides the only alternative to suppressing virus spread in tomato fields.

Lambda-cyhalothrin, zeta-cypermethrin, and cyfluthrin are labeled for thrips suppression and thrips are the target pest for less than 5% of their use in fresh market tomatoes and in the central San Joaquin Valley counties. However, other insecticides provide equivalent or better control. Spinetoram and spinosad are especially effective alternatives for thrips control but insecticide resistance in thrips populations are known to occur with these chemicals, so rotating insecticide classes to reduce insecticide resistance risk is an important consideration.

The total number of spinosyn applications that can be made during a season is restricted by their labels at least in part to help with managing spinosyn resistance in thrips populations. Other products that provide better control of thrips than pyrethroids on tomatoes include methomyl, dimethoate, and flonicamid. Unfortunately, methomyl and dimethoate are especially disruptive of natural biological control of other insects such as leafminers. Cyantraniliprole and abamectin are moderately effective and similar to pyrethroids in suppressing thrips populations.

Whiteflies

The most common whiteflies that infest California tomatoes are the greenhouse whitefly (*Trialeurodes vaporariorum*) and the sweetpotato whitefly (*Bemisia tabaci* biotype B). Leaf feeding by the greenhouse whitefly is generally of minor importance except when they occur at high densities. However, the significance of the sweetpotato whitefly has increased dramatically in the San Joaquin Valley in recent years since it spread into the area from southern California. Its feeding results in uneven ripening of fruit that renders them unmarketable. The high densities recently observed in some central San Joaquin Valley tomato fields resulted in some fields having symptoms of uneven ripening of close to 50 percent. Feeding also resulted in collapse of the plant canopy prior to harvest and yield losses due to sunburn of fruit.

In addition to damaging foliage, and in the case of sweetpotato whitefly fruit, whiteflies are of particular concern to growers because both species are known to transmit viruses to tomatoes. The greenhouse whitefly transmits Tomato infectious chlorosis virus, and the sweetpotato whitefly transmits Tomato yellow leaf curl virus. Neither virus has caused damage to tomatoes in California, but Tomato yellow leaf curl virus has recently been detected in California so there is an imminent threat to California tomato growers, particularly given the serious recent San Joaquin Valley outbreaks of sweetpotato whitefly. Crop losses due to Tomato yellow leaf curl virus on both fresh market and processing tomatoes has reached 90% where the virus is present, and the infection occurs shortly after seedling emergence or transplanting. NGNs are the most effective insecticides for suppressing virus transmission since they can protect young plants while providing the residual protection necessary to suppress virus spread. Imidacloprid applied at planting as a soil application or through drip remains the standard method for controlling virus spread by whiteflies worldwide, and dinotefuran applied similarly is equally effective. Whiteflies often require treatment when NGNs are not applied and when their residual activity declines. Foliar sprays of bifenthrin, fenpropathrin, lambda-cyhalothrin and esfenvalerate can suppress whitefly populations and perhaps 5% of pyrethroid sprays used in the San Joaquin Valley target whiteflies.

After bloom, insecticides including spirotetramat, acetamiprid, and spiromesifen can be applied for whitefly control but these are not as effective as NGNs for limiting virus spread. The insect growth regulators buprofezin and pyriproxifen provide control of immature whitefly stages, but they cannot effectively suppress an already large population when used alone.

Garden Symphylan

The garden symphylan, *Scutigerella immaculata*, is a non-insect arthropod that occurs in soils with high organic matter. Symphylans occur in less than 5% of tomato fields but are common in tomato fields in the Sacramento/San Joaquin Delta area as well as in some coastal valley areas. They can be serious problems where they occur, damaging seedlings before or after emergence and stunting the growth of larger plants. The pyrethroids lambda cyhalothrin and cyfluthrin are the most commonly used insecticides for their control and are applied as a soil drench, but diazinon similarly applied is also effective.

False Chinch Bug

The false chinch bug *Nysius raphanus*, is an unusual pest problem that is typically associated with smaller fresh market tomato fields, and especially in the coastal valleys. Their occurrence is unpredictable year to year, and at most 5 percent of fresh market tomato production will be affected in a given year. False chinch bug feeding directly damages small green fruit resulting in lesions that turn dark when the fruit is ripened. They can occur at very great densities when they are migrating from adjacent unmanaged areas when their host plants are drying in spring. Because of field size and timing of when the migration of this pest occurs; treatment is rarely needed on processed tomato fields, however, large populations can occasionally kill tomato seedlings and new transplants in both processing and fresh market fields and can be damaging on the borders of larger fields. Since their migration and resulting damage occurs over a short period of time, the rapid knock down of the migrants provided by pyrethroids make them a preferred control option, and most pyrethroids have similar efficacy in controlling them. The organophosphates dimethoate and malathion provide similar activity and are suitable alternatives.

Beet Leafhopper

The beet leafhopper (*Circulifer tenellus*) is a serious insect pest of both fresh market and processing tomatoes on the west side of the San Joaquin Valley region, and to a lesser extent in the Sacramento Valley. The major concern is transmission of beet curly top virus, which stunts young plants and can result in a virtually complete loss in heavily infected fields. About 50% of the total fresh market and processing tomato acreage in the San Joaquin Valley is at risk for infection in years when insect and virus pressure is high. Spring plantings tend to be most heavily affected. In areas where beet leafhoppers are a perennial problem, they are often controlled with a single preventative soil application of imidacloprid, dinotefuran, or thiamethoxam. When a preventative neonicotinoid is not applied, a foliar application of dimethoate, flupyradifurone, cyantraniliprole, or carbaryl can be used. The pyrethroids lambda cyhalothrin, zeta-cypermethrin, and fenpropathrin have beet leafhopper on their labels and are used on perhaps 5% of tomato acreage for this purpose, but their relative efficacy does not exceed that of the alternative products for control of this insect.

Leafminers

Leafminers, *Liriomyza sativae* and *L. trifolii*, are usually a secondary pest that become a problem late season if their natural enemies have been disrupted by applications of broad-spectrum insecticides earlier in the growing season. They tend to be more problematic on pole tomatoes which have a long fruiting period and are treated frequently to protect the fruit from damage. Extensive leafminer leaf feeding can reduce yield and expose fruit to sunburn through defoliation. All of the pyrethroid products except bifenthrin that are registered on tomatoes are labeled for use against leafminers. Their use for other insects earlier in the season incidentally suppresses leafminer populations. Far less than 5% of pyrethroids are applied specifically to control leafminers, and cyantraniliprole, spinetoram, emamectin benzoate and abamectin are suitable alternative insecticides.

Pyrethroid Use: 2020–2022

Monthly pyrethroid use in strawberries are presented in Figure 24. Most conventional fresh market and processing tomato acreage is treated with pyrethroids, sometimes with several applications each year.

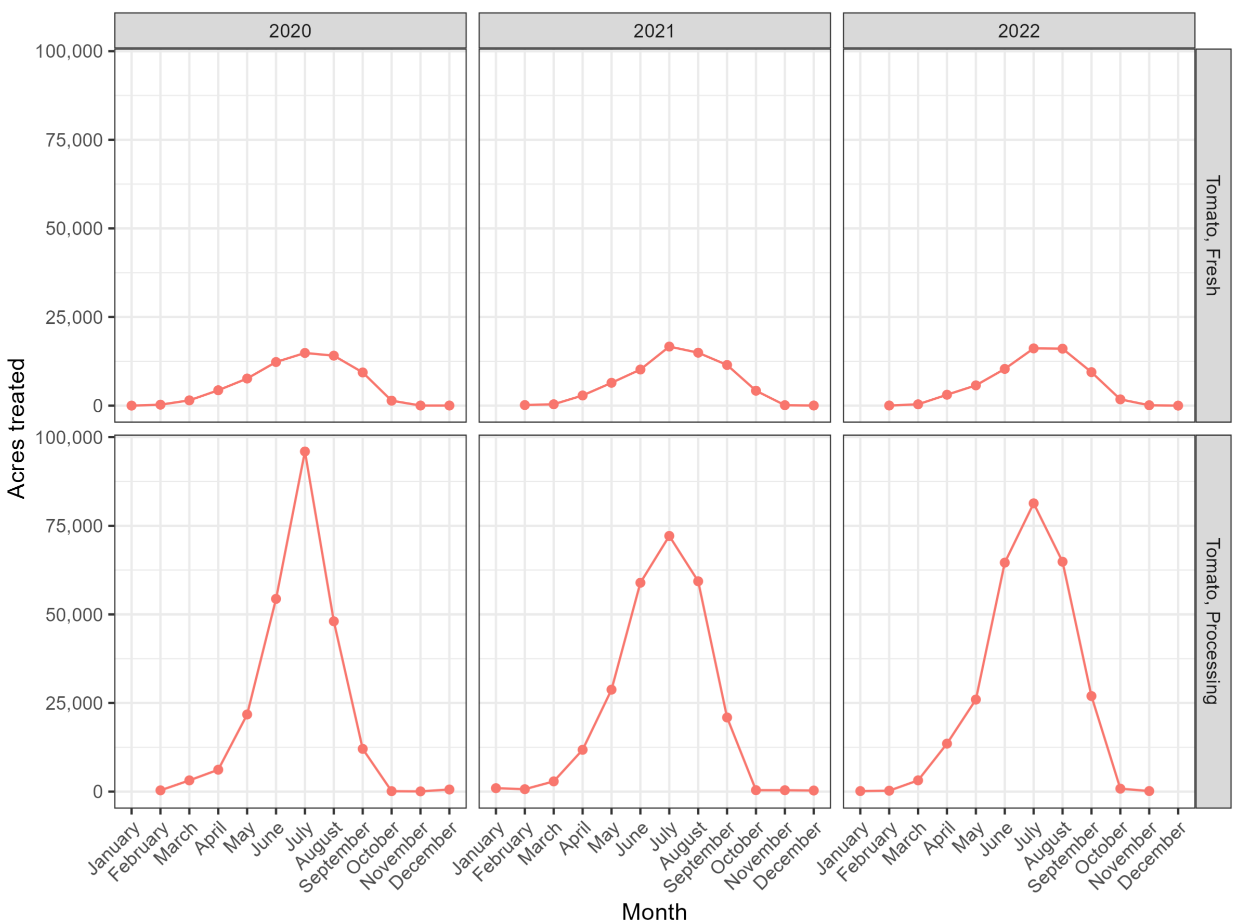


Figure 24: Monthly Use of Pyrethroids: Fresh and Processing Tomato, 2020–2022

Table 47 reports pounds applied, acres treated, and use rates for pyrethroids and alternative AIs in fresh tomato. Lambda-cyhalothrin, imidacloprid, and bifenthrin were the most widely used AIs in terms of acres treated. Out of the pyrethroids, lambda-cyhalothrin was applied on the largest number of acres. Other pyrethroids used in fresh tomato (esfenvalerate, cyfluthrin, zeta-cypermethrin, and fenpropathrin) were applied on fewer acres than most AIs.

Table 47: Annual Use of Pyrethroids and Alternative Active Ingredients in Fresh Tomato, 2020–2022

	Lbs. Applied				Acres Treated				Use Rate (lb/ac)
Active Ingredient	2020	2021	2022	Total	2020	2021	2022	Total	
afidopyropen	128	234	148	510	2,874	5,180	3,213	11,268	0.05
beta-cyfluthrin	347	97	45	489	11,707	3,311	1,814	16,832	0.03
bifenthrin*	1,893	1,721	1,491	5,105	20,564	19,798	16,663	57,025	0.09
buprofezin	347	336	184	867	931	981	543	2,455	0.35
chlorantraniliprole	796	1,232	1,155	3,184	13,002	19,409	16,780	49,191	0.06
cyfluthrin*	51	252	223	525	1,159	5,609	5,003	11,770	0.04
dimethoate	687	678	971	2,336	2,223	3,336	2,812	8,371	0.28
esfenvalerate*	208	270	360	838	4,545	6,108	7,743	18,397	0.05
fenpropathrin*	227	438	357	1,022	1,203	2,164	1,842	5,208	0.20
flonicamid	297	254	358	909	2,373	2,229	2,998	7,600	0.12
flupyradifurone	597	775	559	1,931	3,598	4,326	3,174	11,098	0.17
imidacloprid	3,701	4,338	3,603	11,642	27,253	21,733	17,636	66,621	0.17
indoxacarb	130	67	43	240	2,056	1,078	1,134	4,268	0.06
lambda-cyhalothrin*	657	747	718	2,122	22,523	25,733	24,890	73,147	0.03
methomyl	3,710	7,250	6,156	17,116	5,294	8,968	7,512	21,774	0.79
methoxyfenozide	2,818	3,056	2,090	7,964	14,097	16,337	11,707	42,141	0.19
novaluron	171	215	246	632	2,171	2,745	3,143	8,059	0.08
oxamyl	1,334	2,143	2,162	5,640	1,652	2,743	2,633	7,028	0.80
pymetrozine	71	66	34	172	498	787	251	1,536	0.11
pyriproxyfen	74	238	159	471	1,433	4,075	2,687	8,196	0.06
spiromesifen	219	259	79	557	1,697	1,990	607	4,294	0.13
thiamethoxam	575	426	1,003	2,004	9,729	7,709	10,619	28,057	0.07
zeta-cypermethrin*	26	19	114	160	685	746	4,489	5,920	0.03

*Target Pyrethroids

Table 48 reports pounds applied, acres treated, and use rates for pyrethroids and alternative AIs in processing tomato. Imidacloprid, lambda-cyhalothrin, and chlorantraniliprole were the most widely used AIs in terms of acres treated. Out of the pyrethroids, lambda-cyhalothrin, bifenthrin, and esfenvalerate were applied on the largest number of acres. Other pyrethroids used in processing tomato (cyfluthrin, zeta-cypermethrin, and fenpropathrin) were applied on fewer acres than most AIs.

Table 48: Annual Use of Pyrethroids and Alternative Active Ingredients in Processing Tomato, 2020–2022

	Lbs. Applied				Acres Treated				Use Rate (lb/ac)
Active Ingredient	2020	2021	2022	Total	2020	2021	2022	Total	
afidopyropen	44	569	NA	612	1,036	13,022	NA	14,058	0.04
beta-cyfluthrin	428	253	547	1,228	14,441	8,699	19,453	42,593	0.03
bifenthrin*	8,171	9,323	7,040	24,534	93,866	111,274	80,478	285,618	0.09
buprofezin	471	1,772	244	2,487	1,321	4,712	630	6,662	0.37
chlorantraniliprole	7,238	8,899	7,134	23,271	104,843	122,265	105,970	333,078	0.07
cyfluthrin*	375	248	111	734	8,934	6,002	3,030	17,967	0.04
dimethoate	16,509	19,945	23,881	60,335	49,945	57,679	70,688	178,312	0.34
esfenvalerate*	812	625	638	2,075	16,660	13,199	13,058	42,917	0.05
fenpropathrin*	366	1,146	229	1,741	1,755	5,823	1,098	8,676	0.20
flonicamid	66	64	28	157	678	610	315	1,603	0.10
flupyradifurone	1,296	2,829	382	4,507	7,192	15,574	2,295	25,061	0.18
imidacloprid	27,052	33,434	30,640	91,125	133,231	148,585	138,256	420,072	0.22
indoxacarb	1,373	2,193	1,367	4,933	18,840	27,653	20,845	67,338	0.07
lambda-cyhalothrin*	3,124	3,620	3,473	10,217	111,118	126,073	118,729	355,921	0.03
methomyl	1,974	401	2,676	5,051	2,366	506	3,541	6,413	0.79
methoxyfenozide	11,278	10,921	9,362	31,561	57,823	57,688	45,946	161,458	0.20
novaluron	92	84	220	396	4,667	1,056	3,294	9,018	0.04
oxamyl	48	533	370	951	77	868	550	1,494	0.64
pyriproxyfen	20	30	21	72	333	492	394	1,219	0.06
spiromesifen	44	65	163	272	365	515	1,280	2,160	0.13
thiamethoxam	2,599	6,084	3,787	12,471	49,565	62,773	65,587	177,925	0.07
zeta-cypermethrin*	120	130	127	376	4,189	5,180	2,862	12,231	0.03

*Target Pyrethroids

Economic Analysis

This section presents the expected change in net revenues for fresh and processing tomato if pyrethroid insecticides were to become unavailable. This cost includes the change in pesticide material costs on acres previously treated with pyrethroids. We anticipate no change in application costs. In the absence of any anticipated effect on yields, gross revenues will not change. Consequently, the only impact on net returns is the impact on pesticide material cost.

Tables 49 and 50 present representative products for pyrethroids and alternative AIs used on fresh and processing tomatoes, respectively, in 2020–2022 and their material costs per acre. The material cost per acre is the product of the average use rate (lb/ac) over this period and the price per pound. The average use rate was computed by dividing total pounds applied over the three-year period by the total acres treated. Price per pound of AI was calculated based on the product formulation and product price. For fresh tomato, the cost per acre ranges from $4.51 to $73.55. For processing tomato, the cost per acre ranges from $5.15 to $74.07.

Table 49: Representative Product Cost per Acre: Fresh Tomato, 2020–2022

Active ingredient	**Representative product**	**Cost per acre ($)**
abamectin	Agri-Mek Sc Miticide/Insecticide	10.82
acetamiprid	Assail 70wp Insecticide	9.00
afidopyropen	Sefina Inscalis Insecticide	44.29
bacillus thuringiensis	Javelin Wg Biological Insecticide	17.15
bifenthrin*	Bifenture Ec Agricultural Insecticide	8.18
buprofezin	Talus 70df	73.55
carbaryl	Sevin 5 Bait	16.05
chlorantraniliprole	Coragen Insect Control	30.34
cyantraniliprole	Exirel Insect Control	66.09
cyfluthrin*	Tombstone Helios Insecticide	4.51
diazinon	Diazinon Ag 500	57.99
dimethoate	Dimethoate 400	4.84
dinotefuran	Venom Insecticide	39.76
emamectin benzoate	Proclaim Insecticide	48.07
esfenvalerate*	Asana Xl Insecticide	4.79
fenpropathrin*	Danitol 2.4 Ec Spray	16.39
flonicamid	Beleaf 50 Sg Insecticide	45.80
flupyradifurone	Sivanto Prime	52.38
imidacloprid	Wrangler Insecticide	7.01
indoxacarb	Avaunt Evo Insect Control	29.97
lambda-cyhalothrin*	Warrior II With Zeon Technology	8.78
malathion	Malathion 8 Aquamul	11.40
methomyl	Du Pont Lannate Sp Insecticide	26.20
methoxyfenozide	Intrepid 2f	29.78
novaluron	Rimon 0.83 Ec Insecticide	36.81
pymetrozine	Fulfill	24.68
spinetoram	Radiant Sc	70.03
spinosad	Success	62.17
spiromesifen	Oberon 2sc Insecticide/Miticide	28.80
spirotetramat	Movento	73.27
thiamethoxam	Platinum 75sg	39.12
zeta-cypermethrin*	Mustang Maxx Insecticide	12.17

*Target Pyrethroids

Table 50: Representative Product Cost per Acre: Processing Tomato, 2020–2022

Active ingredient	**Representative product**	**Cost per acre ($)**
abamectin	Agri-Mek Sc Miticide/Insecticide	10.36
acetamiprid	Assail 70wp Insecticide	7.78
afidopyropen	Sefina Inscalis Insecticide	42.64
bacillus thuringiensis	Dipel Df Biological Insecticide Dry Flowable	32.17
bifenthrin*	Bifen 2 Ag Gold	5.15
buprofezin	Courier 40sc Insect Growth Regulator	42.43
carbaryl	Carbaryl Cutworm Bait	29.43
chlorantraniliprole	Coragen Insect Control	32.75
cyantraniliprole	Verimark Insect Control	74.07
cyfluthrin*	Tombstone Helios Insecticide	4.13
diazinon	Diazinon Ag 500	60.65
dimethoate	Dimethoate 400	5.87
dinotefuran	Venom Insecticide	45.30
emamectin benzoate	Proclaim Insecticide	55.97
esfenvalerate*	Asana Xl Insecticide	5.09
fenpropathrin*	Danitol 2.4 Ec Spray	16.76
flonicamid	Beleaf 50 Sg Insecticide	37.58
flupyradifurone	Sivanto Prime	54.15
imidacloprid	Admire Pro Systemic Protectant	19.22
indoxacarb	Avaunt Evo Insect Control	39.00
lambda-cyhalothrin*	Warrior II With Zeon Technology	8.69
malathion	Malathion 8 Aquamul	11.01
methomyl	Du Pont Lannate Sp Insecticide	26.25
methoxyfenozide	Intrepid 2f	30.80
novaluron	Rimon 0.83 Ec Insecticide	20.64
pymetrozine	Fulfill	18.98
spinetoram	Radiant Sc	59.99
spinosad	Entrust Sc	53.18
spiromesifen	Oberon 2sc Insecticide/Miticide	27.93
spirotetramat	Movento	72.64
thiamethoxam	Platinum 75sg	38.40
zeta-cypermethrin*	Mustang Maxx Insecticide	13.88

*Target Pyrethroids

Several adjustments were made to the products included in this analysis. Following the critical use analysis methodology of Steggall et al. (2018), such adjustments are necessary to represent how AIs are applied in practice and their comparative efficacy across products. Besiege is a multi-AI product containing lambda-cyhalothrin and chlorantraniliprole, both of which are used extensively in fresh and processing tomato production. We have removed Besiege as a representative product for both AIs and have divided the area used for each as if separate applications of single-AI products occurred. The use rate of Besiege (0.055 lb/acre) is lower than the second most used product Coragen (0.091 lb/acre), however it is expected that a higher use rate of chlorantraniliprole would be necessary to replace the efficacy of the multi-AI product Besiege. Tomato production also includes use of Minecto Pro, a product containing both abamectin and cyantraniliprole. Minecto Pro is the highest used product for cyantraniliprole applications, but only $\tilde{2}$% of abamectin use. Additionally, the price of Minecto Pro ($3.60/oz) is close to the price of other cyantraniliprole products used like Exirel ($3.51/oz). For this reason, we have retained Minecto Pro as the representative product for cyantraniliprole, with it's proportion of abamectin use represented by increases in use of the abamectin-only product, Agri-Mek SC Miticide/Insecticide.

Tables 51 and 52 provide the acreage shares for the alternatives used on fresh and processing tomatoes, respectively, from 2020 to 2022. The second column reports the acreage share treated with each alternative AI when pyrethroids are available. Averaged over the three-year period 2020–2022, pyrethroids represented 26.3% of the total applications to fresh tomato and 24.4% of applications to processing tomato acres treated with either pyrethroids or an alternative AI. Prohibited applications of pyrethroids were replaced proportionately with alternatives AIs. The third column reports the share of each alternative in the composite alternative used to replace applications of unavailable pyrethroids. The most applied alternative AI is imidacloprid, accounting for 10.2% of fresh tomato acres treated and 14.2% of processing tomato acres with pyrethroids or its alternatives.

Table 51: Average Annual Acreage Shares of Alternative Insecticides with and without Pyrethroids: Fresh Tomato, 2020–2022

Active ingredient	**Pyrethroids available (%)**	**Pyrethroids unavailable (%)**
abamectin	7.9	10.8
acetamiprid	3.0	4.0
afidopyropen	1.7	2.3
bacillus thuringiensis	1.7	2.2
buprofezin	0.4	0.5
carbaryl	3.3	4.5
chlorantraniliprole	7.5	10.2
cyantraniliprole	3.4	4.7
diazinon	0.8	1.1
dimethoate	1.3	1.7
dinotefuran	1.7	2.3
emamectin benzoate	0.4	0.5
flonicamid	1.2	1.6
flupyradifurone	1.7	2.3
imidacloprid	10.2	13.9
indoxacarb	0.6	0.9
malathion	0.3	0.4
methomyl	3.3	4.5
methoxyfenozide	6.5	8.8
novaluron	1.2	1.7
pymetrozine	0.2	0.3
spinetoram	8.3	11.2
spinosad	1.1	1.5
spiromesifen	0.7	0.9
spirotetramat	0.9	1.2
thiamethoxam	4.3	5.8
Total	**73.7**	**100.0**

Note: Three-year average from 2020–2022.

Table 52: Average Annual Acreage Shares of Alternative Insecticides with and without Pyrethroids: Processing Tomato, 2020–2022

Active ingredient	**Pyrethroids available (%)**	**Pyrethroids unavailable (%)**
abamectin	7.9	10.4
acetamiprid	3.9	5.1
afidopyropen	0.7	0.9
bacillus thuringiensis	1.2	1.6
buprofezin	0.2	0.3
carbaryl	6.4	8.4
chlorantraniliprole	11.2	14.8
cyantraniliprole	0.3	0.4
diazinon	0.8	1.0
dimethoate	6.0	7.9
dinotefuran	1.1	1.4
emamectin benzoate	1.6	2.1
flonicamid	0.1	0.1
flupyradifurone	0.8	1.1
imidacloprid	14.2	18.7
indoxacarb	2.3	3.0
malathion	0.5	0.7
methomyl	0.2	0.3
methoxyfenozide	5.4	7.2
novaluron	0.3	0.4
pymetrozine	0.0	0.0
spinetoram	3.3	4.3
spinosad	1.0	1.3
spiromesifen	0.1	0.1
spirotetramat	0.2	0.3
thiamethoxam	6.0	7.9
Total	**75.6**	**100.0**

Note: Three-year average from 2020–2022.

Tables 53 and 54 show costs per acre for target pyrethroids and the composite alternative, whose cost we use as a representative material cost if pyrethroids were unavailable. For tomato, switching to the composite alternative would increase material costs for all pyrethroids users. For fresh tomato, the per-acre cost would increase by 610% cyfluthrin users, 569% for esfenvalerate users, 292% for bifenthrin users, 265% for lambda-cyhalothrin users, 164% for zeta-cypermethrin users, and 96% for fenpropathrin users. For processing tomato, the per-acre cost would increase by 565% cyfluthrin users, 444% for esfenvalerate users, 434% for bifenthrin users, 216% for lambda-cyhalothrin users, 98% for zeta-cypermethrin users, and 64% for fenpropathrin users.

Table 53: Costs per Acre for Target Pyrethroids and the Composite Alternative: Fresh Tomato, 2020–2022

Active ingredient	**Cost per acre ($)**	**Cost increase for switching to composite alternative (%)**
bifenthrin	8.18	292
cyfluthrin	4.51	610
esfenvalerate	4.79	569
fenpropathrin	16.39	96
lambda-cyhalothrin	8.78	265
zeta-cypermethrin	12.17	164
composite alternative	32.06	-

Table 54: Costs per Acre for Target Pyrethroids and the Composite Alternative: Processing Tomato, 2020–2022

Active ingredient	**Cost per acre ($)**	**Cost increase for switching to composite alternative (%)**
bifenthrin	5.15	434
cyfluthrin	4.13	565
esfenvalerate	5.09	444
fenpropathrin	16.76	64
lambda-cyhalothrin	8.69	216
zeta-cypermethrin	13.88	98
composite alternative	27.48	-

Tables 55 and 56 summarize the annual change in total pesticide costs owing to the unavailability for each of the three base years. For fresh tomato, the total increase in costs would have been between $1.20 million and $1.44 million. In percentage terms, costs would have increased between 285.9% and 296.0% on acreage treated with pyrethroids that would have been prohibited. For processing tomato, the total increase in costs would have been between $4.44 million and $5.42 million. In percentage terms, costs would have increased between 280.5% and 291.9% on acreage treated with pyrethroids that would have been unavailable. As with the other focal crops, pyrethroids being considerably cheaper than alternative AIs results in a large increase in treatment costs for tomato growers if pyrethroids were unavailable.

Table 55: Change in Treatment Costs due to the Unavailability of Pyrethroids: Fresh Tomato, 2020–2022

Year	Pyrethroids available ($)	Pyrethroids unavailable ($)	Change in cost ($)	Change in cost (%)
2020	421,030	1,624,844	1,203,814	285.9
2021	487,016	1,928,715	1,441,699	296.0
2022	499,341	1,943,851	1,444,511	289.3

Table 56: Change in Treatment Costs due to the Unavailability of Pyrethroids: Processing Tomato, 2020–2022

Year	Pyrethroids available ($)	Pyrethroids unavailable ($)	Change in cost ($)	Change in cost (%)
2020	1,583,326	6,024,727	4,441,401	280.5
2021	1,658,211	6,499,229	4,841,019	291.9
2022	1,929,985	7,351,823	5,421,838	280.9

References

Bakhtavoryan, R., Capps Jr, O., Dharmasena, S., et al. (2022). A household-level demand system analysis of nuts in the United States. *Agricultural and Resource Economics Review*, 51(2):283–310.

CDFA (2023a). 2022-2023 California Agricultural Statistics Review. https://www.cdfa.ca.gov/Statistics/PDFs/2022-2023_california_agricultural_statistics_review.pdf.

CDFA (2023b). California Agricultural Exports 2022-2023. https://www.cdfa.ca.gov/Statistics/PDFs/2022-2023_california_agricultural_exports.pdf.

CDPR (2014). Final Decision Concerning Reevaluation of Certain Pyrethroid Pesticide Products. www.cdpr.ca.gov/wp-content/uploads/2025/01/ca2014-07.pdf.

CDPR (2023). Pesticide Use Reporting. https://www.cdpr.ca.gov/pesticide-use-in-california/pesticide-use-reporting/.

CDPR (2025a). In the Matter of Application for Certificate of Emergency Pursuant to Food and Agricultural Code section 12833 for Transform CA. https://www.cdpr.ca.gov/wp-content/uploads/2025/06/2833_order_of_director_sfx_cotton.pdf.

CDPR (2025b). SEMIANNUAL REPORT SUMMARIZING THE REEVALUATION STATUS OF PESTICIDE PRODUCTS DURING THE PERIOD OF JANUARY 1, 2025, THROUGH JUNE 30, 2025. https://www.cdpr.ca.gov/wp-content/uploads/2025/11/ca2025-13.pdf.

Cloyd, R. (2012). Indirect effects of pesticides on natural enemies. In *Pesticides-Advances in chemical and botanical pesticides*. IntechOpen.

Demkovich, M., Siegel, J. P., Higbee, B. S., and Berenbaum, M. R. (2015). Mechanism of resistance acquisition and potential associated fitness costs in Amyelois transitella (Lepidoptera: Pyralidae) exposed to pyrethroid insecticides. *Environmental entomology*, 44(3):855–863.

Ferrier, P. M., Zhen, C., and Bovay, J. (2023). Price and welfare effects of the food safety modernization act produce safety rule. *Journal of Agricultural and Resource Economics*, 48(1):82–102.

Gajendiran, A. and Abraham, J. (2018). An overview of pyrethroid insecticides. *Frontiers in Biology*, 13:79–90.

Godfrey, L. D., Davis, C., Pierce, T., and Shafter, C. (2006). Influence of late-season insects on the development of sticky cotton in pima and acala cotton in California. In *Proc. Beltwide Cotton Conf., San Antonio, TX*, pages 3–6.

Goodhue, R., Mace, K., Tolhurst, T., Tregeagle, D., Wei, H., Rudder, J., Grafton-Cardwell, B., Grettenberger, I., Wilson, H., Van Steenwyk, R., et al. (2020). Economic and pest management evaluation of nitroguanidine-substituted neonicotinoid insecticides: Eight major California commodities.

Grafton-Cardwell, E. E. (2020). Management of Asian citrus psyllid in California. In *Asian citrus psyllid: biology, ecology and management of the Huanglongbing vector*, pages 250–257. CABI Wallingford UK.

Joyce, A. L., Barman, A. K., Doll, D., and Higbee, B. S. (2019). Assessing feeding damage from two leaffooted bugs, Leptoglossus clypealis Heidemann and Leptoglossus zonatus (Dallas)(Hemiptera: Coreidae), on four almond varieties. *Insects*, 10(10):333.

Kund, G. and Trumble, J. (2016). Effect of insecticides on celery insects, 2014. *Arthropod Management Tests*, 41(1):tsw097.

Matsuo, N. (2019). Discovery and development of pyrethroid insecticides. *Proceedings of the Japan Academy, Series B*, 95(7):378–400.

McRoberts, N. and Grafton-Cardwell, B. (2018). Effective and equitable transport quarantines for bulk citrus movement in California. https://ff968931-a1d7-4042-b2f9-3273043b174e.filesusr.com/ugd/7e4267_0c1528c8c6a04012987deabeb33ca0d4.pdf.

Onstad, D. W. and Knolhoff, L. M. (2022). *Insect resistance management: biology, economics, and prediction*. Academic Press.

Pu, J. and Chung, H. (2024). New and emerging mechanisms of insecticide resistance. *Current Opinion in Insect Science*, page 101184.

Qureshi, J. A. and Stansly, P. A. (2010). Dormant season foliar sprays of broad-spectrum insecticides: An effective component of integrated management for Diaphorina citri (Hemiptera: Psyllidae) in citrus orchards. *Crop Protection*, 29(8):860–866.

Rodbell, E. A., Caron, C. G., Rondon, S. I., Masood, M. U., and Wanner, K. W. (2024). Alfalfa weevils (Coleoptera: Curculionidae) in the western United States are resistant to multiple type II pyrethroid insecticides. *Journal of Economic Entomology*, 117(1):280–292.

Sevik, M. A. and Arli-Sokmen, M. (2012). Estimation of the effect of Tomato spotted wilt virus (TSWV) infection on some yield components of tomato. *Phytoparasitica*, 40:87–93.

Sisman, M. Y. (2016). *Agricultural and Food Policies in Global Trade The Case of Almonds and Hazelnuts*. PhD thesis, Auburn University.

Sobekova, K., Thomsen, M. R., and Ahrendsen, B. L. (2013). Market trends and consumer demand for fresh berries. *APSTRACT: Applied Studies in Agribusiness and Commerce*, 7:11–14.

State Water Resources Control Board, CalEPA (2022). 2020-2022 Integrated Report for Clean Water Act Sections 303(d) and 305(b).

Steggall, J., Blecker, S., Goodhue, R., Klonsky, K., Mace, K., and Van Steenwyk, R. (2018). Economic and Pest Management Analysis of Proposed Pesticide Regulations. In *Managing and Analyzing Pesticide Use Data for Pest Management, Environmental Monitoring, Public Health, and Public Policy*, volume 1283 of *ACS Symposium Series*, pages 20–463. American Chemical Society.

Swegal, H. (2017). The rise and fall of almond prices: Asia, drought, and consumer preference. *Beyond the Numbers: Global Economy*, 6(12):82–102. https://www.bls.gov/opub/btn/volume-6/the-rise-and-fall-of-almond-prices-asia-drought-and-consumer-preference.htm.

Trilnick, I. and Zilberman, D. (2021). Microclimate engineering for climate change adaptation in agriculture: The case of California pistachios. *American Journal of Agricultural Economics*, 103(4):1342–1358.

U.S. BLS (2022). Producer Price Index for Commodities. https://www.bls.gov/ppi/.

US EPA (2008). Updated Spray Drift Language for Pyrethroid Agricultural Use Products.

US EPA (2009). A Review of the Relationship between Pyrethrins, Pyrethroid Exposure and Asthma and Allergies.

US EPA (2011). US EPA Office of Pesticide Programs Pyrethrins/Pyrethroid Cumulative Risk Assessment.

US EPA (2019). US EPA Office of Pesticide Programs' Re-Evaluation of the FQPA Safety Factor for Pyrethroids: Updated Literature and CAPHRA Program Data Review .

US EPA (2020). Pyrethroids and Pyrethrins: Revised Ecological Risk Mitigation and Response to Comments on the Ecological Risk Mitigation Proposal For 23 Chemicals. EPA-HQ-OPP-2008-0331.

USDA Foreign Agricultural Service (2024). 2023 U.S. Agricultural Export Yearbook. https://www.fas.usda.gov/sites/default/files/2024-05/2023%20Ag%20Export%20Yearbook%20Final.pdf.

USDA National Agricultural Statistics Service (2024a). Noncitrus Fruits and Nuts 2023 Summary. https://downloads.usda.library.cornell.edu/usda-esmis/files/zs25x846c/6682zt197/qf85q241d/ncit0524.pdf.

USDA National Agricultural Statistics Service (2024b). Vegetables 2024 Summary. https://www.nass.usda.gov/Publications/Todays_R- eports/reports/vegean25.pdf.

Van Steenwyk, R. and Toscano, N. (1981). Relationship between lepidopterous larval density and damage in celery and celery plant growth analysis. *Journal of Economic Entomology*, 74(3):287–290.

Van Steenwyk, R., Wise, C., Hernandez, A., and Poliakon, R. (2015). Control of Peach Twig Borer in Almonds, 2014. *Arthropod Management Tests*, 40(1):D22.

Zalom, F. (2008). Challenges of managing Lygus in strawberry plantations on the central coast of California. *J. Insect Sci*, 8(49):26–27.