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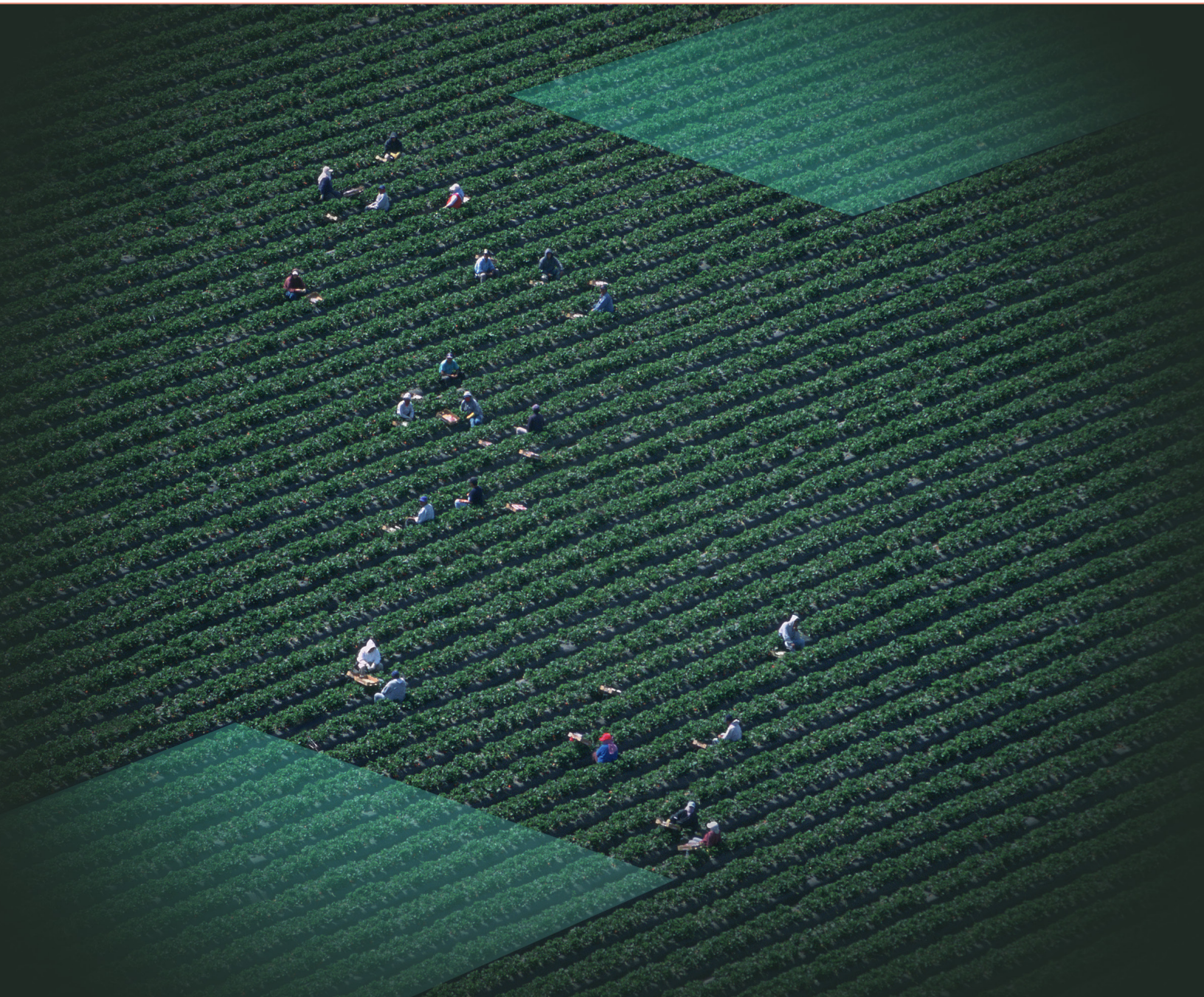
Supplement to Adjusting to Higher Labor Costs in Selected U.S. Fresh Fruit and Vegetable Industries: Case Studies

Linda Calvin, Philip Martin, and Skyler Simnitt



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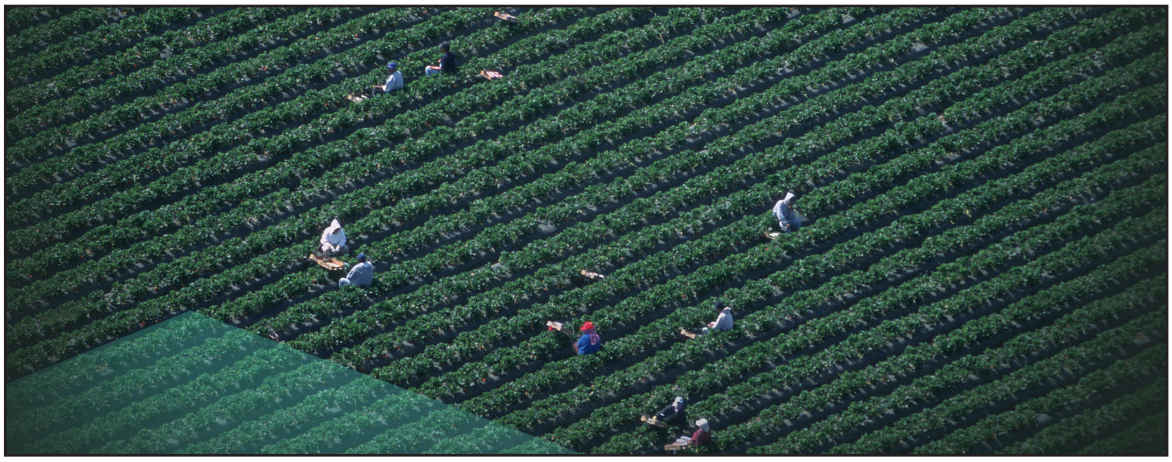

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Abstract

The report *Adjusting to Higher Labor Costs in Selected U.S. Fresh Fruit and Vegetable Industries* examines how U.S. producers of major labor-intensive fresh fruit and vegetables are addressing the rising costs of labor. Farm labor costs are increasing for several reasons, including fewer newly-arrived unauthorized workers, rising State minimum wages, and new requirements to pay overtime wages to some farm workers. Short-term options to meet the labor needs on farms include management changes, such as picking fields and orchards less often and introducing mechanical aids that increase worker productivity. Long-term options include the use of more labor-saving mechanization, additional H-2A guest workers, and reducing overall domestic production. *Adjusting to Higher Labor Costs in Selected U.S. Fresh Fruit and Vegetable Industries* provides an analysis of the ways in which producers are using different tools to address higher labor costs. This related report—*Supplement to Adjusting to Higher Labor Costs in Selected U.S. Fruit and Vegetable Industries*: *Case Studies*—analyzes adjustment options for four major fruit and three major vegetable and melon commodities.

Keywords:

automation, farm labor, fruit, guest workers, H-2A program, harvest, imports, mechanization, specialty crops, vegetables, melons

Note to Readers

This supplement includes several case studies to reinforce the more general discussion contained in *Adjusting to Higher Labor Costs in Selected U.S. Fresh Fruit and Vegetable Industries* (EIB-235). The included case studies provide information on production, trade patterns, and current labor use and alternatives to hand labor in four fresh fruit and three fresh vegetable commodities.

Acknowledgments

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Contents

Introduction

In the United States, labor remains a major factor in the production of produce crops. The USDA, National Agricultural Statistics Service's (NASS) 2017 Census of Agriculture data indicated labor costs account for up to 38.5 percent of total production expenses in the fruit and tree nuts sector and 28.5 percent in the vegetable and melons sector (Castillo et al., 2021). The U.S. farm labor market appears to be tightening, as signaled by growth in agricultural wages outpacing wage growth in comparable nonagricultural industries (Castillo et al., 2021; Zahniser et al., 2018; Calvin et al., 2022). The associated USDA, Economic Research Service's (ERS) report—*Adjusting to Higher Labor Costs in Selected U.S. Fresh Fruit and Vegetable Industries* EIB-XXX—discusses much of the existing literature on the options growers can use to address rising labor costs: (1) increasing use of H-2A guest workers; (2) using mechanical harvesters, if available; and (3) reducing production if a crop becomes non-competitive with imports.[1] The case studies in this supplement discuss production and trade patterns, current labor usage and costs, and alternatives to hand labor in four fresh fruit—apples, grapes, blueberries, and strawberries—and four fresh vegetable and melon commodities—lettuce, melons, and tomatoes.

[1] The H-2A program allows U.S. farmers who anticipate labor shortages to be certified by the U.S. Department of Labor (DOL) to recruit and employ foreign guest workers to fill seasonal farm jobs by satisfying three major criteria. First, farmers must create job offers that satisfy DOL wage and other criteria; if they find too few domestic workers to fill these jobs, they may be certified to employ H-2A guest workers. Second, employers must cover specific costs for their H-2A workers, including travel to the United States and housing costs while the workers are employed in the United States. Third, farmers must pay at least the State's Adverse Effect Wage Rate (AEWR), which ranged from nearly $12 to over $16 per hour across States in 2021, to ensure domestic workers are not adversely affected by H-2A workers.

Washington Apples

Washington is the largest apple producer in the United States, and 75 percent of the State's apples are sold fresh. Over the period spanning 2000/2001–2002/03, average fresh utilized production of Washington grown apples was 3,967 million pounds.[2] However, by the period spanning 2017/18–2019/20 average fresh utilized production had increased 38 percent to 5,458 million pounds (table A-1). Apple-bearing acreage increased 5 percent between the same periods, but yields increased 29 percent due to new varieties and technologies. The Washington apple industry is using new dwarf rootstocks, new orchard architecture, new varieties, and new mechanical aids.

Table A-1
Apple industry statistics, marketing years 2000/2001–2002/03 and 2017/18–2019/20

	Units	Average		Percent change
		2000/2001–2002/03	2017/18–2019/20	
Washington total utilized production	Million pounds	5,383	6,928	35
Washington fresh utilized production	Million pounds	3,967	5,458	38
Washington apple-bearing acreage	Acres	161,000	169,000	5
Washington apple yield	Pounds per acre	33,400	43,033	29
Washington fresh-market share	Percent	74	75	2
Washington fresh-market price	Dollars per ton	429	753	76
Washington processed-market price	Dollars per ton	71	175	146
U.S. total utilized production	Million pounds	9,301	10,571	14
U.S. apple fresh utilized production	Million pounds	5,700	7,358	29
U.S. fresh apple per capita availability	Pounds	16	18	7
U.S. fresh apple imports	Million pounds	378	296	–22
U.S. fresh apple imports as a percent of fresh-market availability (weight)	Percent	4	3	–30
U.S. fresh apple exports	Million pounds	1,388	1,919	38
U.S. fresh apple exports as a percent of production (weight)	Percent	14	18	23

Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Non-Citrus Fruits and Nuts Survey.

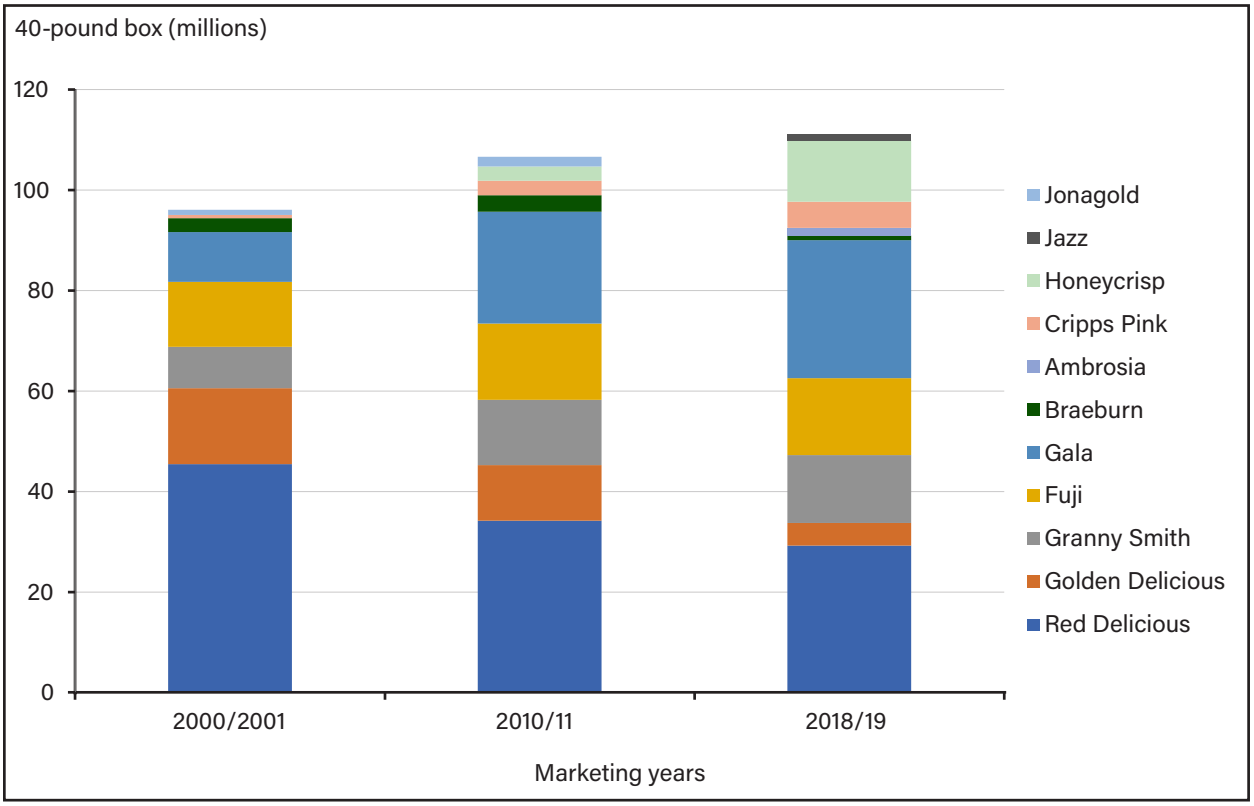
Fresh apples led fresh fruit in availability at 18 pounds per capita over the period spanning 2017/18–2019/20, a 7-percent increase over the period spanning 2000/2001–2002/03. Much of the growth in U.S. fresh apple production is exported—as reflected in the 38-percent increase in apple exports over the past 20 years. Exports—especially to Canada and Mexico—made up 26 percent of U.S. fresh apple sales (2017/18–2019/20). In recent years, 46 percent of U.S. apple exports went to those two countries. The export share of supply availability for

[2] The marketing year for apples begins in August and ends in July of the next year.

fresh apples increased from 14 to 18 percent between the two periods. Supply availability is domestic production plus imports. Over the two decades spanning the periods 2000/2001–2002/03 to 2017/18–2019/20, fresh apple imports to the United States declined 22 percent.

Harvest processes somewhat vary depending on apple variety. In marketing year 2000/2001, Red Delicious accounted for 46 percent of fresh apples (by weight) in Washington and—in 2018/19—this apple variety still led with 25 percent of the crop, followed closely by Gala, Fuji, Granny Smith, and Honeycrisp (figure A-1). Red Delicious apples are usually harvested with just one pass through the orchard and they are the easiest and cheapest variety to pick. Honeycrisp apples, which are increasing in acreage, may require up to four or five passes through the orchard because they do not uniformly ripen. If apple prices are high enough, however, these multiple picks are economically worthwhile (figure A-2).

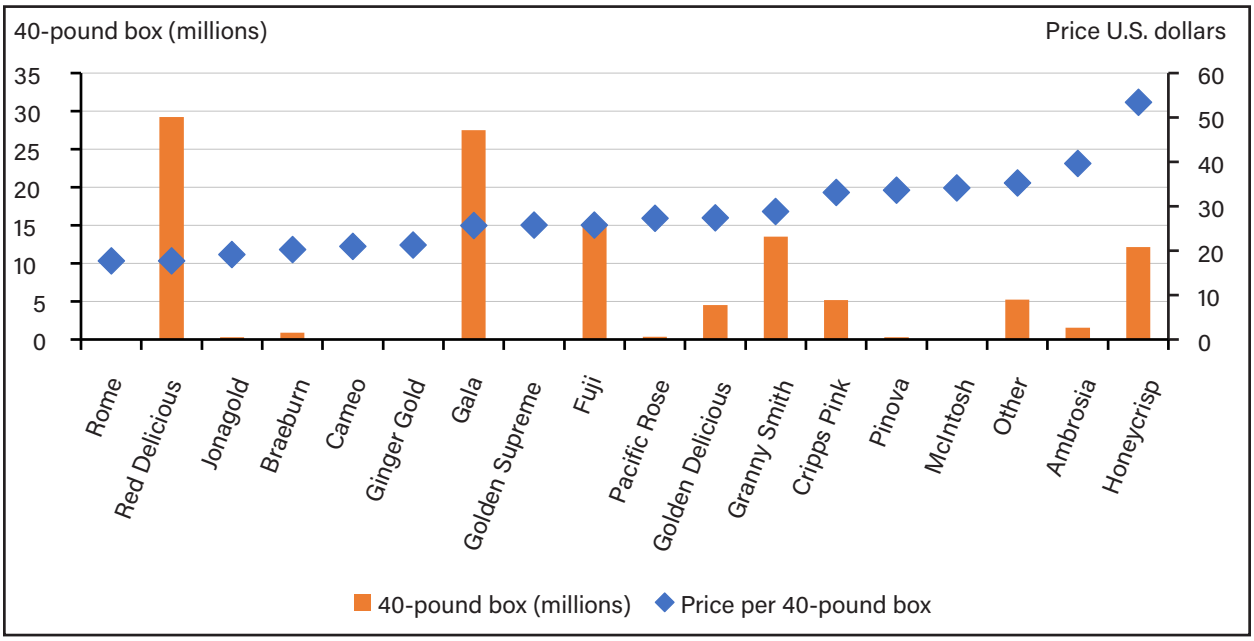
Figure A-1
Changing Washington apple varieties, by season



Note: The marketing year for apples begins in August and ends in July of the following year.

Source: USDA, Economic Research Service and Washington State Tree Fruit Association, Annual Statistical Review of Washington Apple Shipments.

Figure A-2
Volume and prices by variety of Washington apple, marketing year 2018/19



Source: USDA, Economic Research Service and Washington State Tree Fruit Association, Annual Crop Summary 2018/19 Marketing Season.

Apple Labor

There are limited data about the workers who pick Washington apples, but industry sources estimate there are 40,000 to 50,000 seasonal harvest workers, including 20,000 H-2A guest workers. Several organizations provide H-2A workers for growers or help growers navigate the bureaucracy and recruit workers in Mexico. Cost-of-production studies for five varieties of apples grown in Washington in 2019 found labor costs were 22.7 percent of variable production costs for Fuji and 27.9 percent for Honeycrisp. Harvest costs—as a percent of total labor costs—ranged from 28.5 percent for Granny Smith to 34.8 percent for Honeycrisp (Galinato and Gallardo, 2020a–2020e). In 2021, Washington's minimum wage was $13.69 per hour, and workers picking fruit under piece-rate wages typically earn at least 20 percent more than the minimum wage, or $16 to $18 per hour. The U.S. Department of Labor's (DOL) agricultural online wage library listed Washington's piece-rates as $20 to $28 per bin to pick apples in 2021 (U.S. Department of Labor, 2021c).

Traditionally, apples were hand harvested by workers who climbed ladders that leaned into trees. They picked apples into bags or buckets that hung over their shoulders and dumped full bags into large bins and received credit for each bin picked. Working from ladders in orchards on uneven ground can be dangerous, and workers spent up to a third of their time moving and positioning ladders rather than picking.

Newer apple orchards usually grow dwarf trees whose limbs are supported by various types of trellises rather than a thick trunk—making the picking process two-dimensional rather than three-dimensional—and are pruned to expose more of the total leaf area to the sun. Trees put their energy into making apples rather than trunks and limbs, thus raising yields and bringing new orchards into production sooner.

In these new orchards, ladders can be replaced by mechanical aids such as self-driving or tractor-pulled platforms that transport both the workers and apple-collecting bins, eliminating the need for pickers to move and climb ladders. The use of platforms accelerated after 2005, and in 2010 about 11 percent of growers used them (Gallardo and Brady, 2015). Growers have replaced ladders with platforms for pruning (89 percent of growers), training tree limbs (66 percent), thinning (60 percent), trellis construction (43 percent), and phero-

mone placement (29 percent). Workers were paid hourly wages for nonharvesting tasks.[3] [4] Only 1 out of 35 growers used the platforms for harvesting, however. There are no data on how many platforms are currently in use, but industry sources call them ubiquitous, especially in relatively flat areas and for nonharvest activities (Gallardo, 2021).

Piece-rate wages are more common in harvesting, which affects the adoption of platforms. Crews using platforms often have eight workers including four on the platform to pick apples from the upper branches from two adjoining rows of trees and four on the ground to pick the lower branches. All platform workers deposit apples into shared bins, so platform picking crews share a group piece-rate wage that reflects the number of bins they pick. Apple pickers are guaranteed the minimum a wage rate and share a bonus if the group picks more than a minimum number of bins per hour or day, which provides an incentive to work fast. Since slow workers can bring down the group piece-rate wage, at least one grower experimented with letting crews pick their crewmembers (Ross, 2016).

The fastest ladder pickers prefer to work individually rather than share piece-rate wages with other workers on the platform, so using ladders is a grower strategy to attract fast-picking workers (Gallardo, 2021). There appears to be more resistance to working on platforms among local workers than for H-2A workers, who must accept their work assignments (Gallardo and Brady, 2015). New H-2A workers without apple-picking experience might be safer on platforms, where they are paid by the hour—i.e., the Adverse Effect Wage Rate (AEWR)—with a bonus offered if the group picks more than the target number of bins per hour or day.[5] Platforms enlarge the pool of labor since a lack of strength is no longer an obstacle to apple harvesting.

Researchers in New York found platforms increased the productivity of harvest workers, which is critical when weather or other events make fast harvesting necessary.[6] In 2019, one large firm in Washington used 62 platforms in the field in one day to harvest late-season Pink Lady apples before a forecasted freeze, and the firm was able to pick at night by putting lights on the platforms.

Various operation-specific factors determine whether platforms for harvest will lead to profitable outcomes: orchard architecture, apple varieties, labor force, and growers' skill at managing labor under a new payment system. Managers' strategies to increase workers' acceptance of platforms include developing new financial incentives to workers, such as bonuses for night work (Ross, 2016). Researchers in New York found once employees used platforms for harvesting, most did not want to go back to ladders, which involved more exhausting work (Wells et al., 2017).

[3] These adoption rates are not surprising. Baugher et al. (2009) found that worker productivity on platforms for apples in Washington showed large gains for all nonharvest activities, ranging from 19 percent for green fruit apple thinning to 67 percent for trellis top string placement.

[4] Gallardo and Brady (2015) reported their sample comprised a higher share of smaller growers than is proportional to the true population of Washington growers. This may have had some effect on their reported results. Also, they used the number of growers rather than the number of acres; it is possible that one grower out of 35 could represent a larger share of acres.

[5] The Adverse Effect Wage Rate (AEWR) was developed to ensure H-2A workers do not adversely affect domestic workers' wages in similar jobs. Economic theory suggests that adding to the supply of labor could depress wages, so the AEWR is a special minimum wage that must be paid to H-2A workers to avoid wage depression.

[6] In New York State, researchers found efficiency gains of 13.0–16.8 percent in 3 trials in 2015 and no gains in 2 trials in 2016 (Wells et al., 2017). The researchers noted that the trials with efficiency gains were composed of workers who had experience using the machines and working as a team. For the trials with no efficiency gains, the workers had little experience with this type of picking.

Alternatives and Outlook

There are two major options to reduce the cost of harvesting apples: (1) pick by hand and improve worker productivity with mechanical aids such as platforms and (2) use robotic arms to harvest individual apples.[7] Both harvesting systems function best if orchards grow dwarf trees and limbs are trained to produce fruit on various kinds of trellises. The grower-funded Washington Tree Fruit Research Commission (WTFRC) was established in 1969 and is funded by growers to conduct research that benefits the apple industry. The WTFRC released a technology roadmap in 2000 to promote the development of mechanical aids, and one result was the platform to replace ladders. Two firms developed harvesting platforms that are used in Washington apple orchards.[8]

Zhang et al. (2020) describe two robotic apple harvesters in development by two startups.[9] They were initially funded by WTFRC, but both now have private investors. A major research initiative is focused on developing harvesters that imitate human vision and hand dexterity to find the ripe fruit, pick individual apples, transport them to the bin, and fill the bin. Researchers are integrating the components that perform each task to increase accuracy and speed. There are tradeoffs between accuracy and speed in machine picking that can be minimized by growing apples on trellis systems—which makes it easier to use artificial intelligence, as well as light detection and ranging (LIDAR) technology—to find and pick ripe apples (Jia et al., 2020).

Over the next decade, a rising share of fresh apples are likely to be harvested by domestic and H-2A workers using platforms to increase their productivity. Improving detection and grasping technologies—combined with the falling cost of electronics—are likely to accelerate the development of selective harvesters. In fresh apples, H-2A guest workers may serve as a bridge to a future of selective harvesting machines.

[7] Efforts to use shake-and-catch technology to harvest apples did not work because of excessive bruising of fruit. Packers typically allow up to 5 percent bruised apples per load for fruit going to the fresh market, which makes the bar very high for successful shake-and-catch technologies (Zhang et al., 2020).

[8] In 2018, most platforms cost $60,000 to $80,000 (Ross, 2018).

[9] The earliest research on mechanical apple harvesters date back to the 1970s. Perfecting apple harvesting has been a long process for machines that operate in fields with variable conditions—lighting, water, dust, and vibration (Zhang et al., 2020).

Grapes

Grape varieties are usually selected for a particular use—i.e., wine, raisin, table, or juice. Some varieties are multi-use—like Thompson Seedless—which dominated in California vineyards until the mid-1960s because this variety could be eaten fresh, dried into raisins, or crushed for wine or grape juice (Alston et al., 2020; Goodhue et al., 2008). The wine industry changed in the mid-1960s when vintners began to label wines by the variety of grape used to make them, such as Chardonnay and Cabernet Sauvignon grapes. Raisin and table-grape growers are planting new varieties to facilitate mechanization and to satisfy consumers. For example, new raisin grape varieties have traits that make them amenable to mechanical harvest; some varieties ripen sooner and some can dry into raisins while on the vine. There are numerous new table grape varieties. In 2019, the California Department of Food and Agriculture (CDFA) reported acreage of 79 named table grape varieties compared with 39 varieties planted in 2000 (CDFA, 2020a).

Wine Grapes

California produces 85 percent of U.S. wine. Most wine grapes are grown in the San Joaquin Valley, although many of the most expensive and famous wines are from Northern California counties such as Napa and Sonoma. Washington and Oregon are also important wine-producing States. Most of the wine produced in California (87 percent) goes to the domestic market and the rest is exported. The United States is the fourth-largest producer of wine but has been the world's largest consumer market since 2010—with total wine sales of $75 billion—including $44 billion of California wine in 2019.

In 2020, California's wine industry grappled with overproduction (Rural Migration News, 2020b). A record wine-grape harvest of 4.5 million tons in 2018 was followed by a 4.1 million-ton harvest in 2019. Due to overproduction, some Napa Cabernet grapes sold for only $1,500 per ton in 2019, which was a decrease from $5,000 per ton in 2018. In 2019, some 200,000 tons of wine grapes were not harvested because growers could not find buyers. Low prices for grapes encourage growers to reduce labor costs (Zhuang et al., 2019a; Smith et al., 2017). Growers are also contending with the effects of climate change (including wildfires), which could change optimal wine grape production zones (Hannah et al., 2013).

Wine Grape Labor

The grower price of wine grapes differs based on the variety, region where the grapes were grown, and other factors such as final use (CDFA, 2020a). In 2019, Napa growers (District 4 in the CDFA's California grape pricing districts) received an average of $5,769 per ton for 159,721 tons of wine grapes. In the San Joaquin Valley, Fresno growers (District 13) received an average of $301 per ton for 1.1 million tons of wine grapes in 2020. Grower-price differences influence production decisions. San Joaquin Valley wine grapes were almost all machine harvested for $325 per acre in 2020, while some Napa and Sonoma grapes were hand harvested at a cost of $1,500–$2,000 per acre. The size of vineyards may influence mechanization decisions. The 2017 Census of Agriculture reported producers in the San Joaquin Valley averaged more than 140 acres of grapes, whereas those on the North Coast averaged 36 acres.

The main hand tasks involved in producing wine grapes are pruning grape vines in winter, thinning bunches in spring, and harvesting grapes in fall (Zhuang, 2019). Pruning and thinning are increasingly mechanized and more than 80 percent of California's wine grapes are mechanically harvested. The share of wine grapes mechanically harvested grew with more efficient machines and higher labor costs (Alston et al., 2020).[10] Hand harvesting wine grapes involves workers who cut bunches of grapes into tubs that hold 40 to 50 pounds and dump the tubs in 1,000-pound bins that are conveyed to the winery for destemming and crushing. A

[10] Mechanical harvest is also common in Washington vineyards with at least 80 percent of wine grapes mechanically harvested (Hansen, 2016).

crew of workers normally divides the per-ton piece rate, and in 2020 most harvest workers earned at least $20 per hour in Napa and Sonoma Counties.

In the early 1960s, two professors at Cornell University and two New York grape growers developed a workable mechanical harvester. In 1972, 103 harvesting machines were used (Hernandez, 2017; Johnson and Rogers, 1974). Machine harvesting is facilitated by pruning and training vines so the plant's foliage is contained within 6 to 8 inches of the trellis wires, making the bunches of grapes more accessible to the rods and fingers of the mechanical harvester that knock off the grapes and transport them to gondolas traveling alongside the harvester. Since wine grapes will be crushed just after harvest, damage to the grapes from the mechanical harvester is acceptable. The cost of machine picking does not increase as yields rise, whereas the cost of hand-picking increases as yields rise because workers are paid a per-ton piece rate. Machines can operate efficiently at night and be calibrated to remove stems and leaves in the field, which reduces labor needs in the winery.

The availability of hand labor varies by location.[11] For example, in the San Joaquin Valley, labor is usually adequate, which explains why pruning is often done by hand during the winter months, when there is little alternative farm work available despite mechanical pruners. Labor costs are higher in Napa and Sonoma counties, and fewer workers are available due to the high cost of living.[12] Many winemakers whose wines sell for very high prices insist vineyard work be done by hand, which may reflect perceptions of what consumers expect. The University of California-Davis developed a "no touch" vineyard at its Oakville Experimental Station in Napa that is completely mechanized and produces higher yields of better-quality fruit with machines, but some growers and wineries continue to use hand labor (Lutz, 2019).

Alternatives and Outlook

As labor costs rise, there could be more mechanization in wine grape vineyards. Vineyards planted on steep hills—and those not designed for mechanization—continue to rely on hand workers, but such vineyards make up a relatively small share of total wine grape acreage. In Napa and Sonoma counties, H-2A workers could continue to hand harvest grapes for employers with appropriate housing. The global oversupply of wine suppressing grower prices and trade conflicts leading to tariffs on wine make it difficult to predict whether the import share of U.S.-consumed wine will rise above current levels.

Raisin Grapes

Nearly all U.S. raisin vineyards are in California. Raisin shipments (i.e., sales) declined by 20 percent from the average of the marketing years 2000/2001–2002/03 to marketing years 2017/18–2019/20 (table A-2).[13] This is likely because consumers can access a wide range of year-round fresh fruit and a large selection of dried fruit that compete with raisins, such as dried cranberries, cherries, blueberries, and various tropical fruit. In addition, rising labor costs and competition from raisins from Turkey shrunk the raisin industry.

[11] Hertz and Zahniser (2013) found evidence of regional variation in labor shortages.

[12] A 2018 survey of over 600 vineyard workers and 50 supervisors in Napa County found that 65 percent of the year-round workers and 85 percent of seasonal workers lived outside the county, where housing costs were lower (Hobbs et al., 2020; Rural Migration News Blog, 2020c). In 2018, most of the workers who were interviewed earned $15–$20 per hour, well above the State's minimum wage of $11 per hour at the time. Some vineyard management companies are hiring H-2A workers if they can provide the free housing required for guest workers. A few vineyards in Sonoma County built housing for H-2A workers but more are planting and replanting vineyards in ways that permit vineyard tasks to be mechanized.

[13] The marketing year for raisins in the United States begins in August and ends in July of the following year.

Table A-2
Raisin industry statistics (dry weight), marketing years 2000/2001–2002/03 to 2017/18–2019/20

		2000/01–2002/03	2017/18–2019/20	Percent change
Shipments	Million pounds	649	519	–20
Per capita availability	Pounds per person	1.5	1.3	–18
Imports	Million pounds	31	63	103
Import share of availability (weight)	Percent	5	11	138
Exports	Million pounds	240	167	–30
Export share of supply availability (weight)	Percent	35	29	–19

Sources: USDA, Economic Research Service and the Raisin Administrative Committee.

The United States was the world's largest producer of raisins until 2016/17, when Turkey became the world's leading raisin producer (USDA, FAS, 2018). Turkey—where the cost of producing raisins is much lower than in California—is the world's largest raisin exporter. In the past, the U.S. industry depended on State and Federal marketing programs to remain competitive in export markets. There was a two-tier market for domestic and export sales, with a lower price for exports so U.S. raisins could compete with lower-cost raisins from Turkey and other countries. In 2015, the U.S. Supreme Court found this system to be unlawful (Crespi et al., 2015), which made U.S. raisin prices increasingly dependent on Turkish production and exports. Between marketing years 2000/2001–2002/03 and 2017/18–2019/20 imports as a percent of U.S. raisin supply avail¬ability increased from 5 to 11 percent, while U.S. raisin exports declined 30 percent.

Raisin Labor

Harvesting raisins is a race between sugar and rain. Growers wait until the percentage of sugar in the grapes is over 20 percent to begin the harvest, which involves workers wielding knives to cut bunches of grapes, place them in plastic tubs, and dump the tubs on a 2- by 3-foot paper tray positioned on the ground between the rows of vines. Grapes are left in the sun for 2–3 weeks to dry into raisins. After the raisins are dried, the paper trays are rolled or folded, and the dried raisins are gathered and dumped into bins for transport to the packing house.

In this traditional tray system for raisin production, the later the harvest begins, the higher the risk for the drying grapes to be damaged by early-fall rains. With a short period for harvest and drying, growers need thousands of seasonal workers to harvest their grapes. In the San Joaquin Valley, where housing costs are low, growers generally find an adequate labor force, so there are few H-2A workers in raisins.

In 2020, most harvest workers filled about 40 trays per hour, which—at $0.35 per tray—yielded $14 per hour for laborers, more than the State's $13 minimum wage at the time (Martin, 2020). The characteristics of raisin harvest workers are believed to be unchanged from the early 1990s, when more than 90 percent of them were born in Mexico, more than 90 percent were men, they averaged 5 years of schooling, and an estimated 60–70 percent were unauthorized immigrants (Mason, 1998).

Raisin growers, grower organizations, scientists from USDA's Agricultural Research Service (ARS), university scientists, and agricultural equipment companies worked independently and collectively to develop and refine new technologies to reduce labor needs (Fidelibus, 2014). Through 2000, almost all growers hand harvested their grapes and dried them using the traditional tray method. A huge crop in 2000 caused a 56-percent decline in raisin prices. The availability in 2001 of a wine-grape harvester to harvest raisins encouraged the adoption of harvesting machines in the raisin sector.

Two alternatives to the traditional tray-harvest system are currently in use: (1) the continuous tray-harvesting system and (2) the dried-on-the-vine (DOV) system. In 2019, 30 percent of the 147,537 raisin acres were harvested mechanically, including 28,644 acres harvested using the continuous-tray method, as well as another 15,428 acres harvested with DOV technology and various trellis structures (CDFA, 2020b).[14] The continuous-tray system involves workers severing the canes a week before harvest so the grape cluster stems (rachis) dry, making them brittle enough to separate during the mechanical harvest. This keeps the grapes from being torn off the cluster, helping to maintain the integrity of the fruit (Rural Migration News Blog, 2004). A modified wine-grape harvester separates the partially-dried fruit from the vine and drops it onto a conveyer belt that transports the grapes individually to a continuous paper tray, with a worker following behind to help spread the grapes onto the tray. After the grapes dry into raisins in about 2 weeks, the paper tray is picked up by machine and the raisins are transferred to bins.

Continuous-tray harvesting requires less retrofitting and investment in vineyards than the DOV system. Labor costs are 83 percent lower with this system compared with the traditional tray-drying system and yields are similar (Vasquez et al., 2006a and 2006b). Harvest machines can damage old trellises, so trellises must be strengthened, but the major investment is in harvesting machines, which may not be economical for small vineyards. There is, however, a custom mechanical-harvesting industry serving smaller vineyards.

A complete DOV system involves new grape varieties, new trellises, and new cultural practices. When the grapes are ripe, the canes holding the bunches are severed, and the grapes dry into raisins on the vine in about 6 weeks. Since the temperature within the canopy that is 5–6 feet above the soil is substantially lower than on the ground, grapes need to mature by mid-August to dry into raisins before fall rains begin. USDA, ARS played an important role in developing these early-ripening varieties (Fidelibus, 2014).

Canes with bunches of mature grapes can be cut by hand or machine to allow the grapes to dry while still supported by the trellis. Dried grapes can be shaken off the vine by harvesters and transported immediately to packers without additional drying. Dried-on-the-vine vineyards have more vines per acre, partly because there is no need to leave space between the rows to dry grapes into raisins. New vineyards planted for DOV will benefit from much higher yields, often 4 or 5 tons of raisins per acre, depending on trellis design, versus 2 tons per acre in conventional raisin vineyards. Setting up a new vineyard with a new grape variety and a new trellis system to support the severed canes is expensive and certain trellis systems require a unique harvest machine.

The new Sunpreme grape variety dries into raisins on the vine naturally without the need to cut canes (Fidelibus, 2014; Romero, 2015). Since the canes are not cut, the trellis systems used in DOV are not necessary to support the canes. Sunpreme grapes can be grown on smaller and cheaper trellis systems, such as those used with wine grapes, accommodating more vines per acre that can be machine pruned (i.e., nonselective spur pruning), which further reduces costs. Two potential drawbacks to the Sunpreme variety are that up to 20 percent of the grapes are lost because they fall to the ground before or during harvest, and the raisins have a slightly different flavor and color than traditional California raisins.

Alternatives and Outlook

In the early 2000s, 60 percent of raisin growers were over the age of 60 and farmed an average of 70 acres, and a third had a nonfarm job (Rural Migration News Blog, 2005). The aging population of growers on small farms who may not be willing to invest in new and expensive technologies, even if it would reduce labor costs,

[14] Two University of California, Davis scientists developed the continuous-tray method by working with a raisin grower. The grower adopted the continuous-tray system in 1972 and further refined it until other growers began to use the system in 2002. University of California, Davis scientists developed a DOV system in the 1960s, although Australian researchers were already tinkering with a dried-on-the-vine (DOV) system in the 1950s. Australia used a drying emulsion to hasten fruit drying, which led to a lighter-colored fruit with a different taste. California wanted to maintain the traditional California-type raisin, so growers there concentrated on developing early-ripening varieties (Angulo et al., 2007). A few California raisins growers began using the DOV system around 1990.

slows the transition to harvest mechanization. Other factors slowing mechanization include competition from lower cost, imported raisins and the typical availability of generally adequate harvest labor in the Fresno area. When raisin growers act, some replace vineyards with nuts, often almonds, reducing the demand for hand workers because California's nut harvest is mechanized (Rodriguez, 2014; Cline, 2011; Souza, 2020). California's almond-producing acres rose from 510,000 in 2000 to 1.18 million—with another 350,000 nonbearing acres—in 2019 (CDFA, 2020d). Almonds are the most valuable crop grown in California, worth $6.1 billion in 2019 (USDA, NASS, 2020).

Table Grapes

California grows 98 percent of the commercial table grapes in the United States. U.S. production of table grapes rose by 14 percent between marketing years 2000/2001–2002/03 and 2017/18–2019/20 seasons (table A-3).[15] New table grape varieties are bred to use fewer inputs and to attain higher yields. Per capita table grape availability rose by 6 percent between 2000/2001–2002/03 and 2017/18–2019/20, a period during which imports rose by 29 percent and the import share of availability in terms of weight increased from 48 percent to 51 percent. Exports rose by 13 percent, but the export share of supply availability decreased from 23 percent to 22 percent.

Table A-3
U.S. table grape industry statistics for marketing years 2000/2001–2002/03 to 2017/18–2018/19

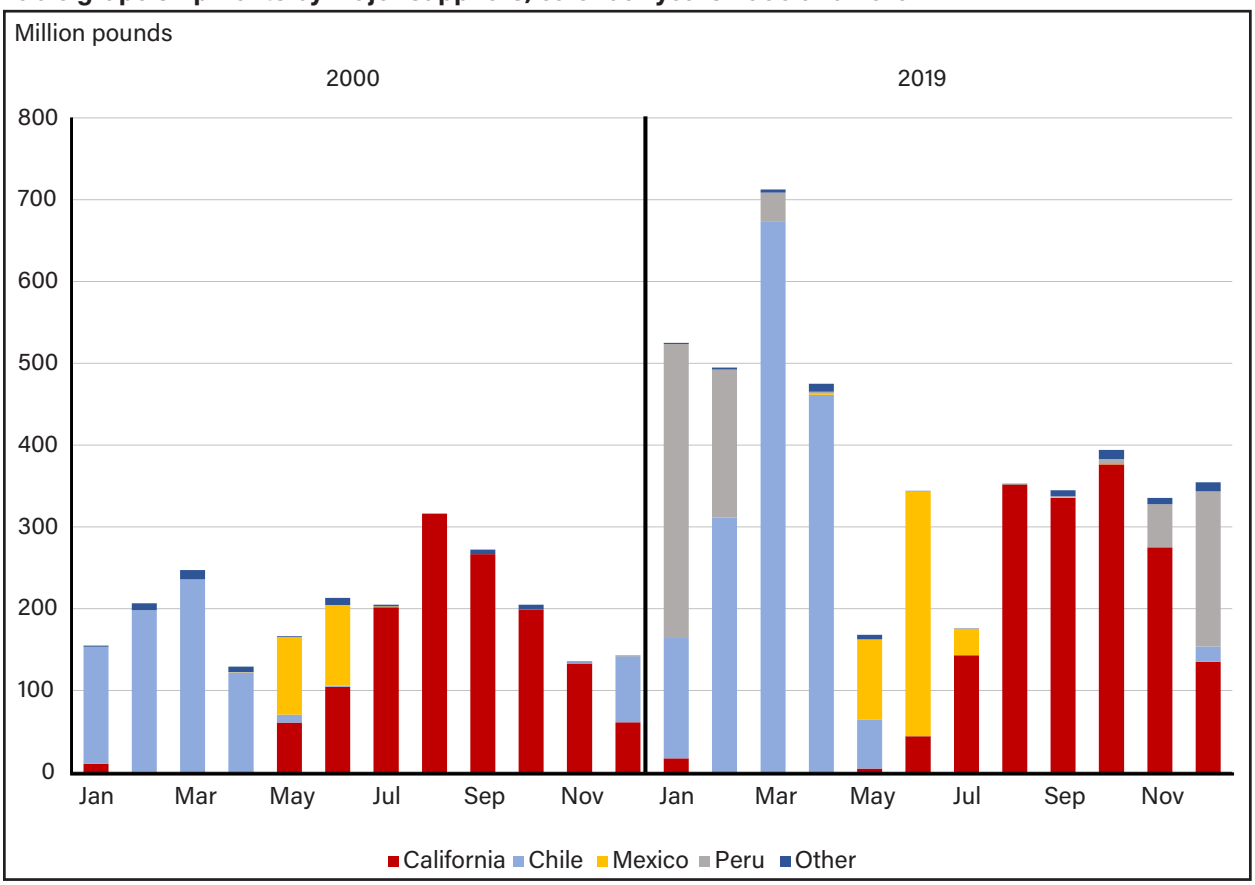
	Unit	2000/2001–2001/02	2017/18–2018/19	Percent change
Production	Million pounds	1,836	2,085	14
Per capita availability	Pounds	7.8	8.2	6
Imports	Million pounds	1,058	1,368	29
Import share of supply availability (weight)	Percent	37	40	8
Exports	Million pounds	672	757	13
Export share of supply availability	Percent	23	22	–6

Source: USDA, Economic Research Service calculations.

Many countries export fresh grapes to the United States, including Chile, Peru, and Mexico. Figure A-3 shows the distribution of shipments in 2000 and 2019. Harvesting seasons are lengthening in the United States and abroad as growers try to capture the high prices that are common at the beginning and end of the season. U.S. shipments in the early season (May–July) from the Coachella Valley declined by 63 percent between 2000 and 2019 as imports of grapes from Sonora, Mexico, continued later in the spring and into early summer. Shipments from the San Joaquin Valley, which begin in late June or early July and end in January, face competition with Mexico in July and competition from Peru in November and December. Despite import competition, San Joaquin Valley table grape production increased 36 percent between 2000 and 2019. Many large grower-shippers import grapes from Chile, Peru, and Mexico to augment their domestic production. In some cases, they may reduce domestic production when imports are cheaper at that time in the season.

[15] The marketing year for table grapes in the United States begins in May and lasts through April of the following year.

Figure A-3
Table grape shipments by major suppliers, calendar years 2000 and 2019



Source: USDA, Economic Research Service using USDA, Agricultural Marketing Service, Market News.

Table Grape Labor

Grapes are a perennial plant bearing fruit once a year. The fruit ripens slowly and not uniformly, so the harvest on one operation with several varieties of grapes can continue for several months. Once harvested, most grapes can be held in cold storage for at least 2 months.

Table grape vineyards are harvested by teams of three, with two pickers cutting bunches of grapes, putting them into plastic tubs, and the third worker using a wheelbarrow to transport the full tubs to a packer at the end of the row. Packers trim bunches on portable tables and place them into the bags or clamshells in which grapes are sold. These packages are then cooled in packing houses before shipping.[16] Some harvesting crews use teams of two people, with both workers beginning the day picking and, after six to eight loads of grapes are picked, one worker begins to pack while the other continues to pick. In 2020, California's minimum wage was $13 per hour, which was the wage guaranteed to table grape harvesters, who also received incentive pay averaging $0.35 ($0.32–$0.38) per box of picked and packed grapes. This wage structure enabled a pair of workers who picked and packed 11 cartons an hour to earn nearly $15 an hour (Martin, 2020).

In California, the table grape workforce is predominantly local and diverse, comprised mostly of Mexican-born workers but including Mexican-American and Filipino-American workers as well. Many couples and extended families harvest table grapes (Martin, 2020). Table grapes are grown in areas with relatively low-cost housing and many farm workers, so few growers employ H-2A workers.

[16] Most table grapes are picked and packed in the field. Some table grapes go to packing houses for this step, especially those that are packed into clamshells. Pickers cut bunches of grapes and place them into picking boxes, which are taken to the packing house to be packed or to cold storage for packing at a later date.

Table grapes are harvested for 8 weeks in the Coachella Valley beginning in late May and finishing in July. Up to 40 percent of Coachella harvesters are employed in pre-harvest tasks between December and May, giving them up to 8 months or 450 hours of work in table grapes. At $15 per hour, the workers earn $6,750 in grape work and few workers move with the harvest. Grape harvesters and packers in the San Joaquin Valley have a longer season, so working 1,000 hours means earning $15,000 per year.

A cost of production study for early maturing flame seedless grapes in the southern San Joaquin Valley estimated the major pre-harvest hand tasks—including pruning vines in the winter, positioning fruiting vines in spring, removing leaves, and thinning grape bunches—require 338 hours of labor per acre (Fidelibus et al., 2018). Harvesting and packing require another 350 hours of labor per acre, for a total of 688 hours of labor per acre. Based on these estimates, California's 121,000 acres of table-type grapes required a total of 83 million hours of hand labor in 2019, which is equivalent to 83,000 workers who average 1,000 hours each.[17] The table grape harvest is harder to mechanize than pruning and thinning, so rising labor costs may encourage the mechanization of nonharvest tasks more than harvest tasks.

There are no table grape harvest machines in development, but a new harvesting aid is commercially available. A robot uses cameras and sensors to move six to eight lugs of table grapes from pickers to the packers at the end of vineyard rows, replacing wheelbarrows and increasing worker productivity, especially as the distance between harvesters and packers increases (Johnson, 2019). Field tests in 2020 showed 1 robot can serve 6 workers, so 10 robots are required for a crew of 60 workers. In 2020, harvest crews with a robot packed 14 percent more boxes than non-robot crews in half rows, 25 percent more in full rows, and over 40 percent more with a central packing station. Harvest workers also reported being less tired at the end of the day (Martin, 2020).

Robot developers want to capture data on grape yields as the machine moves along vineyard rows, add functions such as spraying and cluster thinning, and develop an arm to pick bunches of grapes and put them into tubs. Early users emphasize the robot needs stronger batteries and other refinements to reliably function under dusty field conditions while traveling at least 100 miles per day.

Alternatives and Outlook

Production in Coachella Valley was first to shrink due to competition from grapes imported from Mexico. San Joaquin Valley table grapes face increasing competition from Mexico in the early part of the season, and competition from Peru in the late part of the season. Labor is relatively abundant in California's major table grape production areas, and growers could turn to the H-2A program to hire additional workers if the local labor supply declined. Using an autonomous robot to move grapes to the packing station raises worker productivity and reduces labor costs; however, developing a mechanical harvester to replace hand harvesters appears difficult.

[17] USDA, National Agricultural Statistics Service (NASS) provides data on bearing acres of California table-type grapes, not bearing acres of grapes actually harvested for table grapes, so the labor demand for harvesting table grapes is only approximate.

Blueberries

The United States produced an average of 328 million pounds of fresh-market blueberries and 253 million pounds for processing in calendar years 2017–2019 (table A-4). The two major types of blueberries are cultivated and wild; this case study analyzes the cultivated-blueberries industry. U.S. fresh-market blueberry production is rapidly growing, up 265 percent from 2000–2002 to 2017–19. In 2019, the biggest fresh-market producers (by production share) were Oregon (19 percent), Georgia (16 percent), California (15 percent), Washington (14 percent), Michigan (12 percent), and New Jersey (10 percent).[18] When considering total production for both the fresh- and processed-market blueberries, Washington and Oregon were the two largest producers.

Table A-4
U.S. fresh-market blueberry industry, calendar years 2000–2002 to 2017–19

		Average		Percent change
	Units	2000–2002	2017–19	
Fresh market production	Million pounds	90	328	265
Processed market production	Million pounds	NA	253	NA
Fresh share of utilized production	Percent	NA	56	NA
Fresh imports	Million pounds	44	396	796
Import share of supply availability (weight)	Percent	33	55	67
Fresh exports	Million pounds	40	62	56
Export share of supply availability (weight)	Percent	30	9	–71
Fresh per capita availability	Pounds	0.33	2.02	512

NA = not available.

Source: USDA, Economic Research Service calculations.

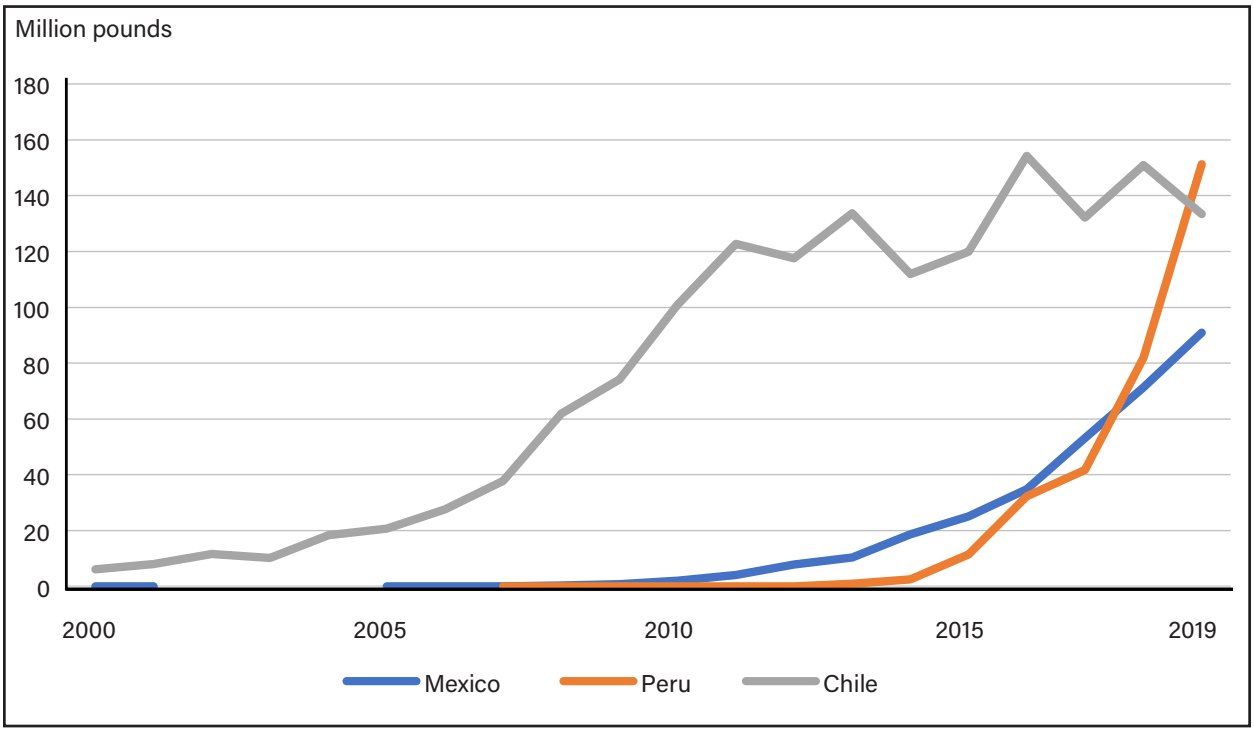
Most U.S. growers hope to produce for the typically higher-priced fresh market and use the processed market for excess and substandard fruit. U.S. harvest seasons are lengthening due to new varieties, even as fresh blueberry imports are available most months of the year, which reduce the periods of high grower prices in the early- and late-seasons.[19]

Both U.S. fresh-market blueberry production and imports have increased (figure A-4). Fresh-market imports increased 796 percent and accounted for 55 percent of domestic availability over the 2017–19 period, up from 33 percent in 2000–2002. Per-capita availability of fresh blueberries increased 512 percent between 2000–2002 and 2017–19.

[18] In 2019, USDA, NASS did not report Florida production due to disclosure rules.

[19] For example, University of Florida breeders developed a low-chill variety of blueberries that can be grown as far south as Immokalee, Florida, and is harvested very early in the season. This variety competes with imports. Some growers are using high tunnels to protect the berries from the elements, which may extend the season. Growers in eastern Washington use mesh protection over their plants to minimize pest damage.

Figure A-4
Growth of fresh-market blueberry imports from Chile, Mexico, and Peru, calendar years 2000–19



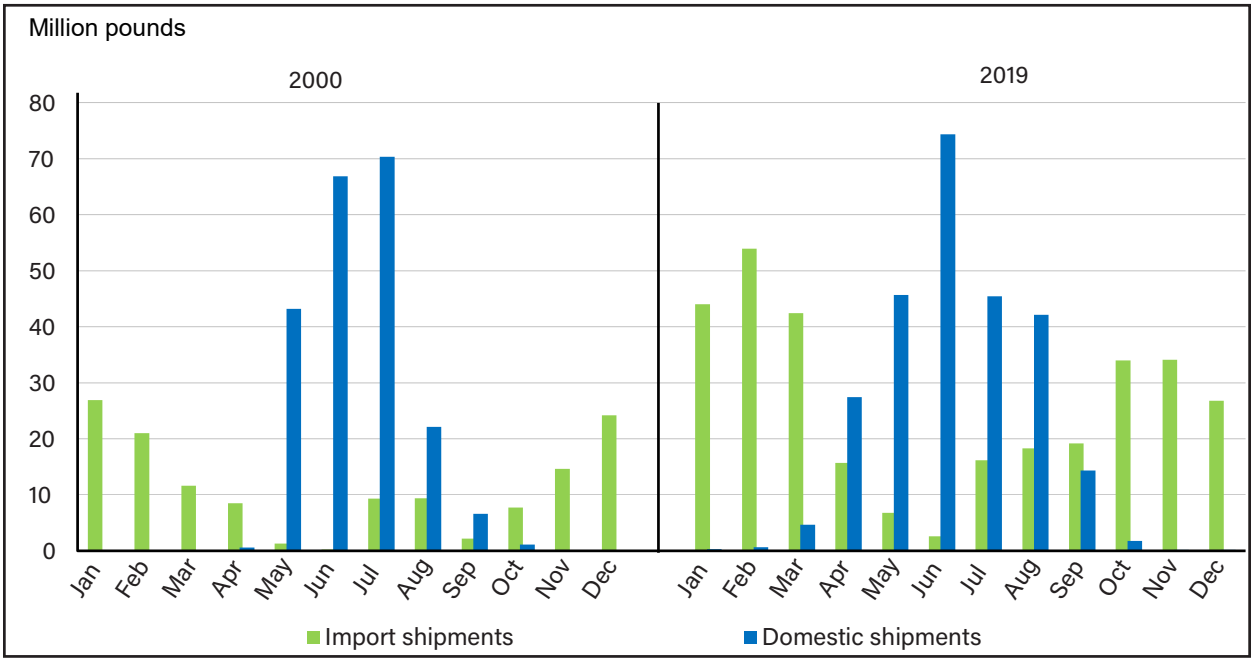
Source: USDA, Economic Research Service using U.S. Department of Commerce, Bureau of the Census data.

Traditionally, Chile shipped fresh-market blueberries to the United States during winter months when there was little U.S. production (figure A-5). Since 2010, Peru and Mexico have been major suppliers of fresh-market blueberries to the United States. In addition, imports from Mexico overlap with the U.S. growing season in spring, and Peru's imports overlap with U.S. growing in the fall.[20] Between calendar years 2015 and 2019, imports from Mexico increased 262 percent and imports from Peru increased 1,212 percent.[21]

[20] Some of the U.S. late-season producers who finish harvesting in September store some of their blueberries to receive higher prices in October. This strategy does not work as well now because of imports from Peru in October.

[21] Chile has reduced late-season blueberry shipments to the United States because of competition from Mexico in the spring.

Figure A-5
Seasonality of fresh blueberries, calendar years 2000 and 2019



Source: USDA, Economic Research Service using USDA, Agricultural Marketing Service, Market News.

U.S. producers have complained about increased blueberry imports—especially in Florida and Georgia—where early-season growers feel the financial impact of imports. In 2020, at the request of the U.S. Trade Representative, the U.S. International Trade Commission (USITC) opened an investigation to determine whether fresh, chilled, or frozen blueberries were entering the United States in such increased quantities as to be a substantial case of serious injury, or the threat of serious injury, to the U.S. blueberry industry. In March 2021, USITC decided imports did not seriously injure the domestic industry, citing increased acreage, production, employment, productivity, shipments, and investments as evidence to the contrary (USITC, 2021). USITC examined the entire industry, not a small group of seasonal producers to determine injury.

Blueberry exports did not increase as much as imports increased, up 56 percent between 2000–2002 and 2017–19. During the 2017–19 period, 89 percent of U.S. blueberry exports went to Canada, whereas the next seven largest markets—South Korea, Japan, United Kingdom, United Arab Emirates, Taiwan, Mexico, and Singapore—accounted for an additional 9 percent.

Blueberry Labor

Blueberries can be harvested by hand or machine. Hand harvesters make multiple passes through a field to pick ripe berries into buckets. Some growers use H-2A guest workers to harvest fresh blueberries, especially in southeastern States, paying them piece-rates of an average of $0.50 per pound in 2021 (U.S. Department of Labor, 2021c).

Harvesting machines straddle the row and use rods and air to dislodge ripe berries that then fall onto conveyor belts, from which they are transported in bins to sheds to be sorted and packed. There are at least six firms manufacturing blueberry harvesters, which cost $200,000 to $300,000. Machine-harvested berries include immature fruit and some bruised fruit with internal damage. The machine can also knock some berries to the ground, which makes them unusable. Blueberries destined for the processing market are more amenable to machine harvesting since damaged berries lacking in appearance and shelf life for the fresh market can be

processed. Pack-out rates for fresh-market berries—the marketable share of fruit arriving from the field—are up to 20 percent lower for machine-harvested fruit (Ratamales and Hancock, 2018). Machine harvesting advocates highlight the damaged berries can be efficiently sorted in packing sheds, so even if more machine-harvested blueberries are diverted to the processing market, labor costs are reduced.

Traditionally, mechanical harvesters were used only for processing blueberries. As harvest labor costs increased and technology improved, more growers began using mechanical harvesters for both fresh and processing blueberries. Some growers use hand labor for the first harvest pass to pick berries for the fresh market and then switch to machine harvesting for subsequent harvest passes when more of the berries go to processing, prices are lower, and hand labor costs increase. Later in the harvest, the fruit on the bushes becomes scarcer, and piece-rates may have to increase as it takes longer for workers to harvest the same amount of fruit.

Alternatives and Outlook

Lower prices due to increased domestic production and increased competition from rising imports make U.S. blueberry growers eager to reduce labor costs. Increasing machine use to harvest fresh-market blueberries would reduce labor costs while also leading to lower yields and pack outs and more bush damage. Manufacturers are modifying machines to reduce damage to berries and bushes.

Growers already using mechanical harvesters for processing blueberries have their fields configured for the machine so they can easily use their harvesters for fresh blueberries. The outlook for the next 5 years is projected to be a cost-price squeeze as labor costs rise and grower prices are held in check by increased U.S. blueberry production and imports. Demand for H-2A labor varies by State, but it is rising in the major blueberry-producing States (U.S. Department of Labor, 2021a).[22] In Washington, most growers have mechanical harvesters for processing berries and—as an alternative—to harvest fresh-market blueberries.

[22] Gallardo and Zilberman (2016) estimated the profitable use of a mechanical harvester for fresh-market blueberries under 2014 conditions required substantial changes in prices, wages, yield losses, and/or quality losses (e.g., bruising).

Strawberries

The United States is a major producer of fresh-market strawberries. It was a net exporter of strawberries until calendar year 2012. In 2019, the U.S. fresh crop was worth $2.3 billion, second in value among fresh fruit after apples. Demand for fresh berries rose with their perceived health benefits and year-round availability (Cook, 2017). Per-capita availability of fresh strawberries increased 78 percent, from 3.4 pounds in the 2000–2002 period to 6.1 pounds in the 2017–19 period. Fresh-market strawberry production increased 83 percent from the 2000–2002 period to 2017–19 (table A-5).

Table A-5
Fresh-market strawberry industry statistics, calendar years 2000–2002 to 2017–19 [1]

	Unit	Average		Percent change
		2000-2002	2017-19	
Utilized fresh production	Million pounds	1,040	1,898	83
Imports	Million pounds	79	378	379
Import share of supply availability (weight)	Percent	7	17	137
Exports	Million pounds	141	287	103
Export share of supply availability (weight)	Percent	13	13	0
Per capita availability	Pounds	3.4	6.1	78

[1]California strawberry production is based on California Strawberry Commission data for 2000–2018 and USDA, National Agricultural Statistics Service for 2019.

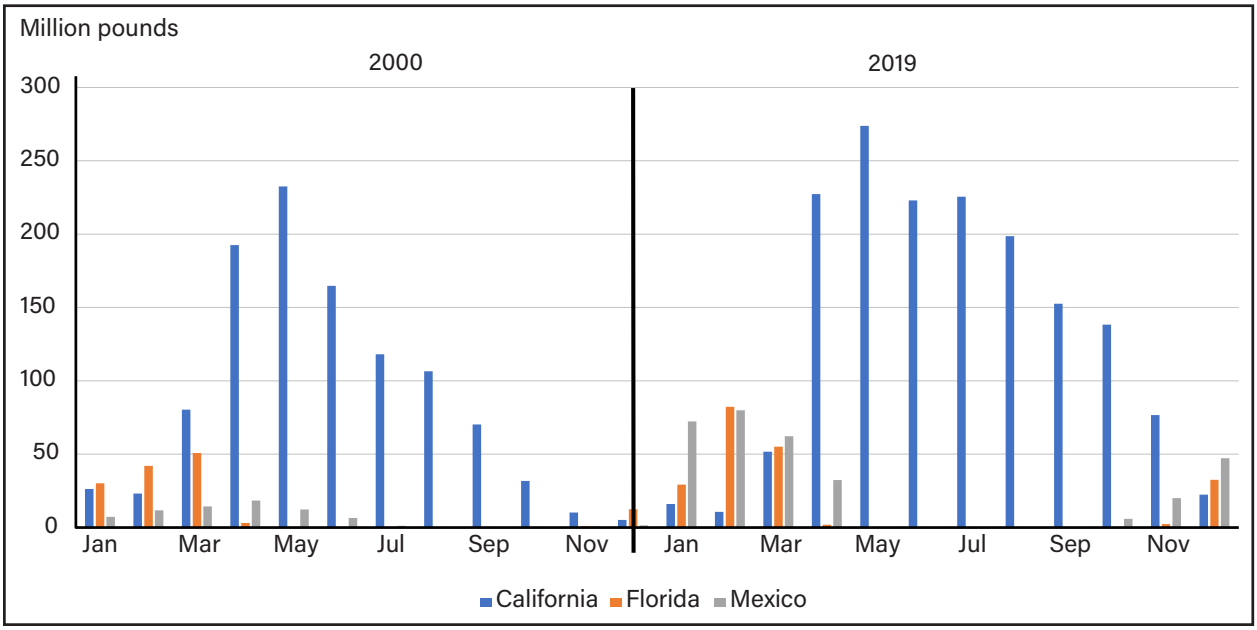
Source: USDA, Economic Research Service; USDA, National Agricultural Statistics Service; and the California Strawberry Commission.

The largest fresh-market-producing States are California and Florida. California markets strawberries all year with lower shipments in the winter. Florida markets strawberries from December through March (figure A-6). California's fresh-market production increased 82 percent between 2000–2002 and 2017–19 (using California Strawberry Commission data). Florida's total production increased 17 percent over the same period, with an assumption that all production goes to the fresh market.[23]

Fresh-strawberry imports increased 379 percent between 2000–2002 and 2017–19. Imports, as a percent share of supply availability, grew from 7 percent to 17 percent between 2000–2002 and 2017–19. Almost all fresh-strawberry imports are imported from Mexico. Mexico is capable of extending the strawberry season since more strawberries are grown under plastic hoops, which protect the fruit from adverse weather (Escobar et al., 2019). Most imports from Mexico come to the United States from November through April, competing directly with Florida and the Southern California production region.

[23] Florida's fresh-market production data are not available for calendar years 2017 and 2019.

Figure A-6
Strawberry shipments, calendar years 2000 and 2019



Source: USDA, Economic Research Service using USDA, Agricultural Marketing Service, Market News.

Comparing calendar years 2000 and 2019, monthly shipments from Florida and Mexico rose in each month of their seasons. However, shipments from California decreased between 2000 and 2019 from January through March and increased in every other month. Competition from Mexico in the winter season and high land costs have reduced strawberry production in southern California. California shipments from the Southern California district (Orange, San Diego, and Coachella areas) region decreased in January through March in 2019 compared with 2000 due to increased price pressure from imports from Mexico during those months and high land costs. In 2000, the Southern California district planted an average of 2,465 acres for winter, spring, and summer production. By 2019, acres planted decreased 91 percent (California Strawberry Commission, 2002 and 2020). Some Southern California district growers expanded in Oxnard, while other growers expanded in Mexico (Burfield, 2021). During the main parts of their seasons, the season pattern remained the same for Florida and Mexico. Florida faces competition with imports from Mexico during the whole strawberry-growing season, but most strawberries from Mexico are shipped to the Midwest as well as western States, whereas Florida's strawberries are largely sent to buyers in eastern States.

U.S. strawberry exports rose by 103 percent between 2000–2002 and 2017–19. However, strawberry exports—as a share of supply availability—remained at 13 percent. In 2019, Canada received 71 percent of U.S. fresh strawberry exports and Mexico received for 16 percent. The U.S.-Mexico strawberry trade is reciprocal.

Strawberry Labor

Strawberries are the most labor-intensive crop grown in California, using about 1.5 workers per acre with 50,000 to 60,000 workers during the peak season (Guthman, 2019). High labor costs are reducing strawberry profitability (Fitchette, 2017). A strawberry field may be picked 40 to 50 times during the harvest season and twice per week during the peak season. Strawberry pickers push a light wheelbarrow—containing plastic clamshells in which strawberries are sold—between two adjacent elevated rows picking from both rows and putting

the strawberries into the clamshells. They take full trays to a checker at the end of the row to receive credit for what was picked and return with an empty tray to pick again. Strawberries must be at least two-thirds red to be picked and packed; non-salable berries are discarded in a bucket attached to the picking cart or on the ground. Even if the berries are not marketable, they must be picked and removed from the field to prevent crop disease.

In 2021, most of California's strawberry workers were paid piece-rate wages—from $1.75 to $2 per flat of eight 1-pound clamshells—and they were guaranteed at least California's minimum wage of $14 per hour in 2021 (Martin, 2021). Some growers offered workers an hourly wage of $5 per hour and a piece rate of $1.25 for each flat, whereas other growers guaranteed workers would earn at least the $14 minimum wage and offered $0.50 per tray after eight trays per hour. Workers typically picked eight or nine flats per hour, enabling most of them to earn more than the minimum wage. Productivity varies with individual skill, plant yields, type of picking cart, and the time of day since workers often pick at a slower rate toward the end of the day as they tire (Anjom et al., 2017).

The strawberry labor market is fluid with some workers monitoring yields with different growers to determine where they are most likely to maximize their piece-rate earnings and changing employers to earn as much as possible. H-2A workers are tied to their jobs, however, and cannot switch employers to increase their earnings. In the past, some growers refused to rehire workers who quit during the season and went elsewhere, but since unauthorized Mexico-U.S. migration declined after the 2008–09 recession, few growers maintain the no-rehire-during-the-season policy (Guthman, 2019).

Roughly 10 percent of Californian strawberries are organic. In 2018, when the State's minimum wage was $11 an hour, piece-rate wages in Oxnard were $1.80 per tray for conventional strawberries and $2.10 for organic strawberries—17 percent higher than conventional piece-rate wages. The higher piece-rate wage for organic strawberry picking compensates workers' wages for lower yields (Sowder, 2021). Workers, however, considered the organic wage premium too low since they reported earning more per hour picking conventional rather than organic berries. Nevertheless, some older workers preferred picking organic berries for hourly wages because they did not want to feel pressured to work fast by the piece-rate wage system (Soper, 2019). H-2A workers are sometimes assigned to organic strawberries since they must work where they are assigned.

Many of the workers harvesting strawberries in the coastal areas of California are authorized and unauthorized Mexican-born workers who have settled in the United States, including non- or limited-Spanish speakers from southern Mexican states such as Oaxaca and Chiapas (Martin, 2020). There are often several members of a family and relatives in a crew, so strawberry crews are more diverse in terms of age and gender than the solo-male work crews who largely harvest tree fruit like apples. Therefore, there is more productivity variance among strawberry harvesters than other crop industries paying piece-rate wages. Most strawberry harvesters are hired directly by farmers rather than brought to farms by farm labor contractors (FLCs). In addition, many farmers keep older and slower workers on their payrolls to retain their younger and faster relatives with whom they live and carpool.

H-2A workers are a rising share of strawberry workers in California partly because of the importance of having a labor force available to pick the highly perishable fruit. Strawberry growers must assess the value of H-2A workers' reliability against the high costs of housing guest workers in the coastal areas where strawberries are grown. Most H-2A employers use motels to house H-2A workers, four workers per room in bunk beds (California Institute for Rural Studies, 2018). The number of H-2A strawberry workers expanded fastest in Santa Maria because of the city's lower housing costs than the Oxnard and Salinas-Watsonville areas. In addition,

some employers are building new housing or remodeling facilities to house H-2A workers. Up to half of the Salinas-Watsonville strawberries may be picked by H-2A guest workers, and berries were the most common type of job filled by U.S. H-2A workers in fiscal year (FY) 2020, accounting for 10 percent of the U.S. jobs certified to be filled with guest workers (Rural Migration News Blog, 2020a).

Labor costs are a major cost of production in California's strawberry industry with harvest costs (a labor-intensive practice) accounting for up to 67 percent of total costs (Tourte et al., 2016). The major labor aid in strawberry picking is a slow-moving conveyor belt traveling in front of berry pickers, allowing them to place full flats of berries on the belt rather than carry flats to the end of the row to receive credit for their work. Research found using the conveyor belt cost growers an average of $1,200 for a 6-day week and reduced paid wages by an average $5,000 per week by using 15 workers instead of 25—an overall savings of $3,800 per week (Rosenberg, 2003). Some growers reduce piece-rate wages by 10–20 percent when workers can place full trays on conveyor belts to reflect the fact that workers can pick more trays (Rural Migration News Blog, 2008).

The conveyor belt was developed by an Oxnard-based custom-fabrication firm and introduced in 2002 (Calvin and Martin, 2010). Conveyor belts are available in many sizes, with some covering only a few rows of berries for up to 5 workers and others covering 12 or more rows for 20–30 workers. Conveyor belts require workers to be similarly productive to improve workers' picking efficiency, and the smaller machines make it easier to assemble crews picking strawberries at the same speed. In 2020, conveyor belts that straddle up to 17 rows of berries were used in Ventura County's strawberry harvest, which allowed workers to pick at least 20 percent faster than traditional methods (Martin, 2020).

Conveyor belts are common in Oxnard, where the ground is flat and fields are relatively large. There are fewer conveyor belts in the Salinas-Watsonville area partly because of hillier terrain. During earlier efforts to introduce the conveyer belt in Salinas-Watsonville, there were disputes about how much the piece-rate wage should be reduced with increased worker productivity causing some workers to distrust growers who use the machines (Rural Migration News Blog, 2008).

An alternative to the conveyor belts is a system of field-assist robots to take full trays from individual pickers and transport them to a collection location, which can improve efficiency even if worker productivity varies. Field-assist robots are relatively simple and inexpensive but must be programmed to anticipate when workers will need an empty tray so the robot arrives with an empty tray at the right time and the picker continues to work without interruption. During a 2018 test in a high-yield period, researchers found 5 field-assist robots could maximize picking efficiency for a 25-person picking crew with a range of picking speeds (Peng and Vougioukas, 2020).

Several efforts were initiated to mechanize strawberry harvesting. One prototype was used in California in 2020 (Hart, 2021). Mechanically harvesting strawberries is difficult because the fruit is soft and easily damaged and fields must be repeatedly picked without damaging plants that continue to produce berries for the rest of the season.[24] The California Strawberry Commission's 2018 Strawberry Automation Summit assembled researchers and firms to promote harvest mechanization efforts. Two early protypes were funded by a consortium of strawberry growers.[25] U.S. growers did not adopt one of the machines because it required strawberries to be planted in a different way, making it uneconomical. The other grower-funded machine prototype is being tested in Florida.

[24] Most strawberry production in Salinas-Watsonville is from April through October, so a damaged plant early in the season would have an impact on the expected yield.

[25] See Delbridge (2021) for an economic analysis of these two machines with respect to standard harvesting; he found neither were economically efficient at the time of analysis.

Private firms raised venture capital to develop machines that pick strawberries, including the one operating in California in 2020. Growers worry whether changes to production (i.e., varieties, harvesting method, etc.) will affect consumer demand, but no buyers have yet reported any adverse reactions to the berries picked by an automatic harvester. Harvester use is limited to early-season berries before the strawberry plant grows more foliage and obscures berries. Machine-picked strawberries must be sorted and packed by hand in the field or in a packing shed. The California Strawberry Commission also has been promoting the development of a machine to cut the strawberry plant runners that drain energy from the plant, so the fewer runners that remain on the plant produce larger berries.

The key actors in the strawberry industry are the marketers or shippers. Four firms market the majority of fresh strawberries. The requirements of these big firms will shape the balance between mechanization, H-2A workers, and less domestic production with more imports (Guthman, 2019). The marketing firms are large and financially stable. They breed and patent superior plant varieties while also developing brand names that allow the berries they market to command premium shelf space and higher prices. Marketers have global strategies to supply berries, importing as needed and working closely with the largest U.S. growers, some of whom grow strawberries in the United States and in Mexico.[26]

Alternatives and Outlook

As growers confront rising labor costs, their first option is to use more mechanical aids to increase the productivity of hand workers. Determining how to divide the labor-cost savings from using conveyor belts between growers and workers and developing smaller conveyor belts could accelerate adoption rates. Using robots to transport packed boxes from the worker to the end of the row could also increase productivity while also resolving the problem of trying to match workers of equal productivity behind a harvest platform. Mechanical harvesters could eliminate concerns about labor availability but must first become competitive with hand pickers.

The second option for growers is to utilize more H-2A guest workers. H-2A workers are younger and more homogeneous. Furthermore, H-2A laborers are committed to the assigned work and location. However, some communities oppose the development of more H-2A housing (Martin, 2021).[27] Local strawberry pickers are largely Mexican-born and often unauthorized immigrants with U.S.-born children (California Institute for Rural Studies, 2018). They do not get free housing and transportation to the fields as do H-2A workers.

There are several future scenarios for U.S. strawberries. One is declining U.S. strawberry acreage and rising imports from Mexico, with imports facilitated by U.S.-based marketers. If mechanical harvesters are developed, another scenario could be a short-term increase in strawberry imports and stable or shrinking U.S. production, followed by increased production in California's coastal areas that provide ideal strawberry-production climates. U.S. production could displace imports of fresh strawberries faster if expansion in Mexico increases farm wages there (Escobar et al., 2019).

[26] The USDA, NASS 2017 Census of Agriculture reported less than 2 percent of farms accounted for 67 percent of U.S. strawberry acreage.

[27] In 2019, Santa Maria, California enacted an ordinance requiring agricultural employers to obtain city permits to house H-2A workers in areas with single-family homes. Federal and State agencies investigated in 2020 and found the city ordinance discriminated against people from a foreign country since almost all H-2A visa holders are from Mexico. A threatened U.S. Department of Housing and Urban Development fine of $400,000 prompted Santa Maria to repeal the ordinance.

Lettuce

In 2019, the U.S. farm value of lettuce, including iceberg lettuce—called head lettuce in USDA statistics—and leaf/romaine combined (i.e., romaine, butterhead, and other leaf types) was $3.5 billion.[28] U.S. consumers' preferences have shifted from iceberg to leaf/romaine lettuces, which can help explain why iceberg production fell by 36 percent between 2000–2002 and 2017–19, while leaf/romaine production increased 51 percent (table A-6).[29] In 2019, the 26 pounds of iceberg and leaf/romaine per capita availability was about evenly divided between the two lettuce types.

Most lettuce is produced by large firms operating year-round in California and Arizona. Some producers only grow under contract to big bagged-salad companies and some grow only for their own proprietary brands, while other firms both grow under contracts and grow for their own brands. Cook (2011) estimated the 4 largest iceberg lettuce producers accounted for 60 percent of production and the 8 largest accounted for 80 percent.

The United States produces iceberg and leaf/romaine for sale as whole heads, known as carton lettuce in the industry, and lettuce for processing for bagged salads. The bagged-salad industry began as a small-scale effort to supply bagged salads to a few restaurants in the 1970s. Controlled atmosphere technologies—developed to preserve apples and other fresh fruit—were adapted to preserve leafy green vegetables. By the 1990s, bagged salads became the major way to market lettuces to the food-service industry and retail consumers (Gullino et al., 2019; Thompson and Wilson, 1999). Restaurants and consumers proved willing to pay premium prices for ready-to-eat salads with nearly a 2-week shelf life. For salad producers, signing contracts to provide bagged salads to retailers and national restaurant chains can stabilize the prices they receive for lettuce.

Table A-6
Lettuce industry statistics, calendar years 2000–2002 to 2017–19

		2000-2002	2017-19	Percent change
Head lettuce (iceberg)				
Production	Million pounds	6,891	4,380	-36
Per capita availability	Pounds	23	13	-41
Imports	Million pounds	61	246	301
Import share of supply availability (weight)	Percent	1	5	506
Exports	Million pounds	393	254	-35
Export share of production (weight)	Percent	6	5	-3
Leaf/romaine lettuce				
Production	Million pounds	2,849	4,314	51
Per capita availability (weight)	Pounds	9	13	52
Imports	Million pounds	34	421	1,152
Import share of supply availability (weight)	Percent	1	9	654
Exports	Million pounds	408	426	4
Export share of production (weight)	Percent	14	9	-36

Source: USDA, Economic Research Service calculations.

[28] Lettuce is the most valuable U.S. fresh vegetable—excluding the value of potatoes, sweet potatoes, and mushrooms.

[29] Fox (2020) discusses potential factors behind this change.

The United States produces lettuce on a year-round basis. Only a small share is imported—about 5 percent of iceberg lettuce availability and 9 percent of leaf/romaine availability in 2017–19. Iceberg lettuce imports increased 301 percent between 2000–2002 and 2017–19, and leaf/romaine imports increased 1,152 percent from very small levels in 2000–2002. Some U.S. salad producers plant lettuce in Mexico to fulfill their U.S. bagged salad contracts if weather or other problems disrupt the supply of U.S.-grown lettuce. During the winter, Central Mexico is at a lower risk of cold weather than Yuma, Arizona, but the region has a higher risk of rain. Exports of iceberg lettuce decreased 35 percent between the 2000–2002 and 2017–19 periods, while leaf/romaine exports increased 4 percent.

Controlled environment agriculture-grown (CEA) lettuce is a new trend. There is one California grower-shipper growing CEA lettuce, but a large California salad company recently invested in a Midwestern CEA lettuce operation (Sowder, 2021). Most CEA lettuce operations are closer to urban centers in the Midwest and East regions, which reduces transportation costs. Typically, it is more expensive to cool a greenhouse than to heat it, so building CEA structures for cool-weather lettuce is more expensive than for warm-weather tomatoes, bell peppers, and cucumbers (Tasgal, 2021).

As outdoor lettuce production in California faces increasing water and land constraints, CEA production may increase. One study compared the cost of California-grown field lettuce in Chicago and New York with CEA lettuce grown near these cities and found the CEA lettuce was 158 to 163 percent more expensive. Water use in CEA operations was 10 percent of what is used to produce California field lettuce (Nicholson et al., 2019). CEA operations are more automated because they operate in a more predictable, indoor environment. One firm claims the consumer is the first person to touch their lettuce (Goodwin and Thompson, 2019).

Lettuce Labor

Different growing regions face different labor demands. The longest harvest period is 6 months in the Salinas area in California between May and October, after which some equipment and workers move to the San Joaquin Valley for the November harvest before shifting to Yuma, Arizona, and the Imperial Valley, California, between December and March. Production returns north in April to the San Joaquin Valley on the way back to Salinas. The majority of workers in Yuma and Imperial Valley are H-2A workers as they replace aging green-card commuters.[30] In addition, there are also increasing numbers of H-2A workers in Salinas. Iceberg and romaine harvest crews are made up of usually 20–26 workers. Typical lettuce wages in 2020 were $15 per hour, about the AEWR that must be paid to H-2A guest workers. Total labor costs were higher—including payroll taxes for Social Security and Federal Unemployment Insurance—nearly $20 per hour for domestic workers and over $20 for H-2A workers who must be provided with transportation and housing (Martin, 2020).

Many innovations reduced the need for pre-harvest labor in lettuce production. Lettuce seedlings are normally transplanted; a plant-tape machine puts seedlings into a belt so they can be transplanted by machine at a predetermined spacing in the field (Mohan, 2017). A thinning machine that knows where plants are located in the row eliminates extra plants by spraying a dose of fertilizer that kills them. Weeding machines use knives, flames, or chemicals to remove vegetation that is not lettuce. These labor-saving machines reduced pre-harvest labor needs by two-thirds (Mosqueda et al., 2017).

Developing lettuce harvesters has proven a more difficult task. All iceberg carton lettuce is hand harvested by workers walking behind a conveyor belt attached to a platform. The workers cut mature heads of lettuce, remove defective outer leaves, and put the heads onto a conveyor belt attached to a platform. At that stage,

[30] During the late-1960s and early-1970s, some ex-braceros received job offers from U.S. farm employers and became authorized immigrants or green-card commuters—workers who live in Mexico but have green cards and commute to work seasonally in the United States.

most heads of iceberg are enclosed in a heat-sealed plastic film and packed into cartons. Almost all iceberg lettuce destined for processing into bagged salads is hand harvested in the field, but the workers also remove the lettuce core before placing the heads on the conveyor belt, where they are deposited in bins for transportation to the processing plant.

About 90 percent of romaine for cartons is hand harvested in a similar manner to iceberg lettuce, but there is no core to remove. About 75 percent of romaine for bagged salads is also hand harvested. Leaf lettuce for cartons is harvested by hand, while it is harvested by machine for bagged salads. Baby leaf lettuces for salads are also machine harvested; one manufacturer estimates the machine reduces harvest costs from $0.28 per pound to less than $0.01 cent per pound (Johnson, 2021). The machine harvests in a once-over fashion with a bandsaw that cuts the lettuce and conveys it to bins on or alongside the machine.

Technical issues slowed the mechanization of the iceberg harvest.[31] Heads of iceberg lettuce present several challenges, including the fact that only 80 percent of the heads are mature during the first pass through the field. Heads of iceberg lettuce are heavy and the head must be lifted before being cut by the machine to avoid leaving dirt on the cut head that would require washing. An earlier effort to mechanize the iceberg harvest for processing used a once-over, water-jet cutting machine. Lettuce growers were interested, but the company did not pursue its initial progress with funding to bring it to fruition and the needs of the industry changed. The industry decided to move coring the iceberg lettuce for bagged salads from the plant to the field. This decision meant lower transportation costs to salad plants, and the development of modified atmosphere technology kept the quality of lettuce that was cored in the field in the same condition as whole heads of lettuce arriving at the plant. Coring by machine is a difficult technical problem, so lettuce destined for bagged salads continues to be hand harvested and cored in the fields.

A local firm developed a mechanical harvester that can be used for carton romaine heads or hearts, or romaine for processing, which is the most common use. The machine uses purified-water jets to cut six rows of romaine lettuce in a once-over fashion and convey the cut heads to workers who ride on the machine and sort and orient heads. Packers place the heads in plastic bins for transport to a salad plant, where the romaine is washed, cut, and bagged.

The romaine machine reduces the harvest crew by half—from 24 to 12—and can harvest twice as fast as hand crews—800 pounds per hour rather than 400 pounds per hour (Martin, 2020). This machine—depending on the options included—costs up to $1 million and there are several in operation, including one firm that does custom harvesting (Johnson, 2021). In 2019, utilized romaine production was 2.7 billion pounds. If half is harvested for salads, several hundred workers would be needed to harvest the crop. Since lettuce is continuously planted and harvested, fewer machines are needed than if the lettuce crop is harvested all at once. As machine usage increases, improvements will likely occur over time, while the productivity of hand crews is unlikely to change.

[31] Political issues also slowed mechanization. Like the processing tomato industry in California, the lettuce industry was concerned about the labor situation when the Bracero Program ended. In the 1960s and 1970s, agricultural engineers from USDA, Agricultural Research Service and the University of California, Davis worked on a mechanical harvesting machine that would identify mature lettuce heads and selectively harvest them. However, this research ended following the lawsuit over the mechanical processing tomato harvester. The California Lettuce Research Board wanted to support this research, but the then-governor of California would not allow it (Calvin and Martin, 2010).

Alternatives and Outlook

Lettuce firms tend to be large and privately owned, which can affect mechanization. Although industry leaders cooperate when dealing with governments on issues ranging from food safety to labor, they are competitive in growing and marketing. Firms recognize the rising cost of labor and the need for mechanization, and most firms do in-house research or request machines uniquely suited to their particular needs from manufacturers rather than cooperating for an industry-wide solution.

Melons

The main melons produced in the United States are watermelon with 3.7 million pounds in 2019, cantaloupe with 1.3 million pounds, and honeydew with 0.3 million pounds. This section looks at watermelon and cantaloupe. Growers of these two commodities had vastly different experiences over the last 20 years.

Watermelons

Most watermelons are now seedless, and smaller personal-size watermelons weighing 5 to 7 pounds are gaining market share from larger watermelons weighing 15 to 20 pounds (Agricultural Marketing Resource Center, 2021).[32] Florida, Georgia, Texas, California, Indiana, South Carolina, and Arizona are the leading producers of watermelons. Between 2000–2002 and 2017–19, average U.S. watermelon production declined 2 percent, while average watermelon imports grew 256 percent (table A-7). With domestic production fairly constant, the share of imports in domestic supply availability increased from 11 percent in 2000–2002 to 30 percent in 2017–19. Per capita availability of watermelon increased 10 percent over the same period. In 2019, 87 percent of watermelon imports were from Mexico, followed by Honduras, Guatemala, and Costa Rica. Exports increased 9 percent from 2000–2002 to 2017–19. In 2019, 98 percent of U.S. watermelon exports went to Canada and 1 percent to Mexico.

Table A-7
Watermelon industry statistics, calendar years 2000–2002 to 2017–19

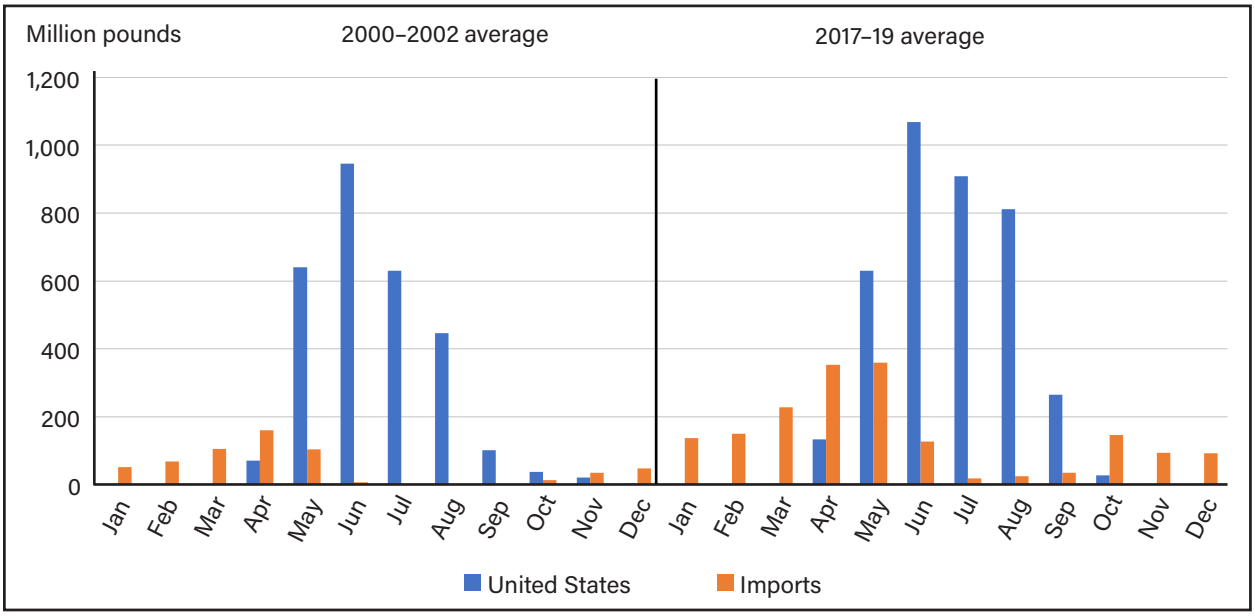
	Unit	Average		Percent change
		2000–2002	2017–19	
Acres harvested	Acres	159,193	107,200	–33
Production	Million pounds	3,919	3,856	–2
Imports	Million pounds	460	1,640	256
Exports	Million pounds	302	329	9
Per capita availability	Pounds/person	14.3	15.8	10
Import share of supply availability (weight)	Percent	11	30	184
Export share of supply availability (weight)	Percent	7	6	-13

Source: USDA, Economic Research Service calculations.

Much of the growth in watermelon imports has been in the off-season for U.S. producers (figure A-7). In 2000–2002, there was some overlap between imports and domestic shipments in April and May, and by 2017–19, imports in these months increased. The largest domestic shippers in these 2 months were Florida and Texas. Since Memorial Day is the second most popular day for watermelon consumption—after the 4th of July—foreign suppliers like to extend their season to Memorial Day, if possible. There is some competition from imports in October at the end of the U.S. season when Texas is still shipping. Florida can sometimes produce a fall crop but, now with competition from imports, it is not usually economical.

[32] According to USDA, Agricultural Marketing Service, shipment data varieties with the name "miniature" (e.g., red flesh miniature, red flesh seedless miniature) increased from only 2 percent of shipments in 2012 to 6 percent of shipments in 2021 from the combined States of California, Florida, Georgia, and Texas.

Figure A-7
Average watermelon shipments over time, calendar years 2000–2002 and 2017–19



Source: USDA, Economic Research Service using USDA, Agricultural Marketing Service data.

Watermelon Labor

Seedless watermelon seedlings are always transplanted into raised beds covered with plastic mulch, with water and fertilizer provided by drip irrigation systems (Boyhan et al., 2017). When sugar levels near the center of the melon approach the right level, field cutters walk through fields, identify ripe melons, use a knife to cut the melons from the stem, and roll them into rows with the pale side up. Loaders walk down the row, pick up melons, and throw or hand them to stackers riding on trucks or old school buses driving through the field. Watermelons are loaded five to seven high in the vehicle; buses are lower to the ground than trucks, making them easier for workers to load. Melons are taken to packing sheds, where they are sized and packed in heavy cardboard bins for transport to retailers. In Georgia, harvesting and hauling costs are about 40 percent of total production costs (Westberry, 2017). Some growers use mechanical aids, such as conveyor belts that trail behind trucks. Loaders pick up and place ripe watermelons onto the belt for transport to a truck that takes them to a shed, or the watermelons move to a packing platform for sorting and packing into bins in the field.

One grower uses a mechanical harvester he developed that requires uniform fields with space for machinery to operate and replaces cutters and loaders. Researchers have developed an experimental machine that uses an audio system to locate and identify ripe watermelons and to cut and roll them into a row for pick up. If this machine is commercialized, it would replace cutters but not loaders (Bushey, 2018).

Among watermelon-growing regions, H-2A workers are most common in the southeastern States. Many H-2A job offers guarantee the AEWR but offer a piece-rate wage to encourage faster work. In 2021, typical piece rates in Florida job offers for H-2A workers were $20 to $30 per busload for field cutters who identify and cut ripe melons. The crew of 10 field loaders and stackers share a piece-rate wage of $80 to $100 per busload of watermelons. To earn $120 per day for 7 hours of work or $13 per hour, the crew must fill 12 busloads per day or almost 2 busloads per hour. Drivers and others paid daily were offered $100 per day for 7-hour days–about $14.30 per hour or slightly more than the AEWR (U.S. Department of Labor, 2021b).[33]

[33] Wage information came from one job order selected as an example from the U.S. Department of Labor's (2021b) website: seasonaljobs.dol.gov.

The decline in domestic watermelon production from 2000–2002 to 2017–19 was 2 percent. With only one grower-developed mechanical harvester in operation, there appears to be little interest from the rest of the industry in labor-saving mechanization that requires fields be reconfigured to accommodate the mechanical harvester. The market for watermelon harvesters is relatively small, which makes it hard to attract significant investments from private machinery firms. Imports from lower income countries will probably continue to put pressure on U.S. producers to reduce their labor costs in certain seasons. Most U.S. watermelons are likely to continue to be hand harvested for the next decade, albeit with more sophisticated mechanical aids that make hand workers more efficient and productive.

Cantaloupe

Cantaloupe consumption is falling—with both domestic production and imports dropping—but domestic production is dropping faster, so the share of imports is increasing. According to USDA, NASS, U.S. production declined by 36 percent from the period spanning calendar years 2000–2002 to 2017–19, while imports declined by 12 percent (table A-8). The major producing States in 2019 were California, Arizona, Georgia, and Florida.

Table A-8
Cantaloupe industry statistics, calendar years 2000–2002 to 2017–19

	Unit	Average		Percent change
		2000–2002	2017–19	
Acres harvested		94,253	59,017	–37
Production	Million pounds	2,228	1,423	–36
Imports	Million pounds	1,099	964	–12
Exports	Million pounds	153	152	0
Per capita availability	Pounds per person	11.1	6.8	–38.6
Import share of supply availability (weight)	Percent	33	40	22
Export share of supply availability (weight)	Percent	5	6	38

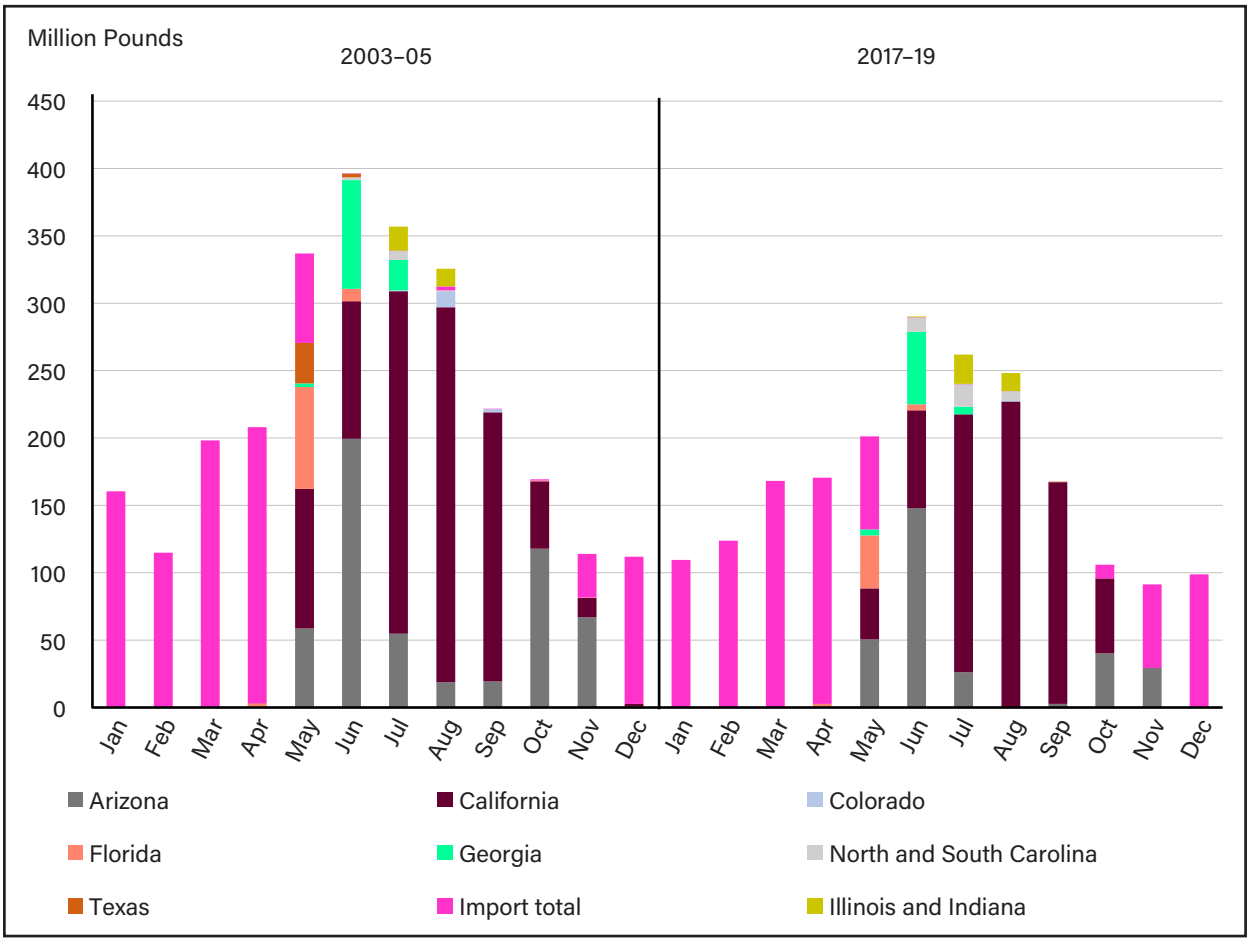
Source: USDA, Economic Research Service calculations.

USDA, Agricultural Marketing Service (AMS) data show domestic cantaloupe shipments declining by 33 percent from the average of 2003–05 to 2017–19 (figure A-8).[34] [35] U.S. shipments declined everywhere except North Carolina, South Carolina, Indiana, and Illinois, but these production areas are small. California shipments declined 45 percent, Arizona declined 24, Georgia declined 40 percent, and Florida declined by 48 percent.

[34] In 2000 through 2002, the largest producing region, San Joaquin Valley, did not report shipments to USDA, AMS so the earlier comparison point in this analysis is 2003–05.

[35] As an industry declines or consolidates, it is harder for USDA, AMS to provide shipment data. If only one or two shippers are in the market in a State at one time, they are unlikely to provide USDA, AMS with important market information.

Figure A-8
Average cantaloupe shipments over time, calendar years 2003–05 and 2017–19



Source: USDA, Economic Research Service using USDA, Agricultural Marketing Service data.

The U.S. shipment season begins in May and ends in December, and producers face competition with imports early and late in the season. In 2017–19, Texas did not produce cantaloupes during the April–June period; Florida production in April–June decreased compared with the 2003–05 period, and Florida's fall crop shrank as well. In California, production in the San Joaquin Valley declined by 18 percent despite no import competition. In the earlier season, California production in the Imperial Valley declined by 41 percent and South California production declined by 70 percent. South Carolina's cantaloupe-production decline is more likely due to import competition.

Central America and Mexico are the main cantaloupe suppliers to the U.S. market. According to USDA, AMS shipment data, average imports between 2003–05 and 2017–19 from all Central American suppliers declined in weight except from Guatemala—the largest supplier—which increased 29 percent. Imports from Honduras, the second largest supplier, declined by 29 percent, while imports from Mexico increased 158 percent from a very small, initial base. Over the same period, the monthly average of both domestic and foreign total shipments decreased every month except February, which was up 8 percent. The other months ranged from a 40-percent decrease in May to a 12-percent decrease in December.

There are several reasons for shrinking cantaloupe consumption, including a series of foodborne illness outbreaks—most notably the 2011 Listeria outbreak linked to Colorado that led to 33 deaths and 1 miscarriage—that may have affected consumer demand (CDC, 2012). Grower costs also increased as buyers demanded stricter food safety protocols. There are new cantaloupe varieties such as Harper types with better

shelf life. Traditionally, California and Arizona growers used the western shipper cantaloupe type, which requires frequent harvesting at full maturity. The Harper-type melon does not produce as much ethylene and does not spoil as fast, so growers can pick fields less often. Growers using Harper-type melons can reduce acreage because there is less spoilage in the marketing chain, so fewer acres are needed to meet the demands of buyers. Although growers benefit from lower labor costs and retailers benefit from less spoilage with the new varieties, it is not clear whether consumers appreciate their crisper texture, which may help to explain declining consumption.

Cantaloupe Labor

Cantaloupe are usually planted from seeds in raised rows, with drip irrigation installed 12–18 inches beneath the surface. Cantaloupe are harvested by workers who follow a conveyor belt or mobile packing table that moves in front of them through the field. The melons are placed on a belt or table that transports them to packers who size and place them into 38–45-pound cartons. Cartons are stacked on pallets and placed in trailers while the fruit is cooled using forced air.

California's cantaloupe fields are picked three to five times during the 2-week period when most melons ripen, down from the daily picks over a 2-week period in the past. Newer varieties such as Harper can be picked in one or two passes through the field (Martin, 2020). A typical field-packing harvest crew is 18–21 people, including 7–9 pickers, 4–5 packers, 2 box makers, 3 loaders, 1 driver, and 1 supervisor. The crew picks and packs 200–300 cartons per hour or 1,800 to 2,700 cartons per 9-hour workday (Martin, 2020).

Most central California growers directly hire harvest workers rather than obtain crews through labor contractors.[36] In 2020, growers paid hourly wages of $13.50 to $14.50, above the State's minimum wage of $13 per hour at the time (Martin, 2020).[37] Adding 30 percent for payroll taxes increased hourly labor costs to at least $17.50 per worker or $368 an hour for the 21-person crew. At 250 cartons per hour, harvest labor costs are $1.50 a carton. Workers employed 50 hours per week at $13.50 per hour earn $675 per week. Relatively few H-2A workers are employed in California's cantaloupe industry because the industry is located in the San Joaquin Valley, where labor is relatively abundant.

California yields ranged from 800–1,000 cartons per acre in 2018–19 (Martin, 2020). If the grower price is $8.75 per carton, a yield of 900 cartons generates gross revenue of $7,875 per acre.[38] Land rent and growing costs are $1,500 per acre or $1.67 per carton, harvesting costs are $1.50 per carton, the cost of the carton is $1 or more, and cooling and marketing costs add $1 per carton. In total, total production costs are $5.15 per carton or $4,655 per acre.[39] One of California's largest cantaloupe growers developed a mechanical harvester that is used only on the developer's farm (Plevin, 2018). The machine picks all the fruit in one pass through the field, covering 12 to 15 acres per day. The machine carries seven sorters to remove unripe fruit and dirt clods, replacing the traditional crew of 30 that follows a conveyor belt and selects ripe melons that are packed in the field. Machine-harvested melons are taken to a packing shed, where 20 percent must be discarded because of defects. At an average 15 acres per day, each machine could harvest 450 acres, and 70 machines could harvest all of California's cantaloupe product if harvested all at once. The harvest moves around the State, as melons ripen first in southern California, then in the San Joaquin Valley, and finally in the more northern Sacramento Valley. Fewer mechanical harvesters would be needed if the machines were moved from area to area as the harvest progressed.

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[36] As the supply of labor decreases, contractors look more appealing. Most labor contractors are providing work year-round, so their pool of labor is more consistent and widely available.

[37] Harvest crews in the California-Arizona desert areas are typically paid piece-rate wages rather than hourly wages. Border-area farm workers are usually authorized workers and eligible for unemployment benefits (Martin, 2020).

[38] The season-average grower price of U.S. cantaloupe in 2018 was almost $23 per hundredweight or $8.75 per 38-pound carton (USDA, NASS, 2020).

[39] Costs have increased over time. Information reported by one grower for 2021 put total costs at $7–$7.50 per carton.

The California cantaloupe grower's experience developing a mechanical harvester highlights several issues common to mechanizing specialty crops. First is the need for uniformly ripening crops that can withstand machine handling. Melons that were bred for yield, disease resistance, and shelf life may have to be modified for optimal machine harvesting—a process that can take years and must gain consumer acceptance. There is no coordinating mechanism so that plant scientists and engineers can cooperate with the entire supply chain to promote mechanization, which is what occurred when mechanizing the processing tomato industry.

Second, the cantaloupe industry and the market for cantaloupe harvesters is small and declining, which makes it difficult to attract significant investments from private machinery firms, prompting growers to design and refine machines they develop with the help of local machine shops. The USDA, NASS 2017 Census of Agriculture reported 685 California cantaloupe and muskmelon growers with 35,600 acres. Fourteen growers with 500 or more acres accounted for 55 percent of the State's cantaloupe acreage. Industry observers contend the seven largest cantaloupe growers largely lead the California-Arizona industry, and these major cantaloupe growers' decisions will determine how the industry manages rising labor costs. The United States is the only high-wage country among the world's leading producers of cantaloupe, so that even the successful development of a U.S. cantaloupe harvester may not generate sufficient sales at home and abroad for manufacturers to justify the necessary investment.

Declining domestic demand and the imports from lower-income countries will probably continue to put pressure on U.S. cantaloupe producers to reduce their labor costs. Most U.S. cantaloupes are likely to continue to be hand harvested for the next decade, albeit with ever more sophisticated mechanical aids that make hand workers more efficient and productive. The alternative would be a once-over harvester that sacrifices marketable yields in exchange for lower harvest costs.

Fresh-market Field Tomatoes

The fresh-market tomato industry in the United States is very diverse. Fresh tomatoes are grouped in several ways, including by variety—round, Roma, cherry, grape, etc. Tomatoes are also classified by harvest maturity—e.g., vine ripe, mature green—and production method (e.g., open field, grown under protection in some kind of CEA structure).

The United States produces both field tomatoes and CEA (mostly active-environmental-control greenhouses) tomatoes and imports tomatoes from Canada—mostly from similar types of greenhouses. The United States also imports tomatoes from Mexico—some are open field tomatoes, and large volumes are CEA tomatoes using a wide range of technologies. Mexico's production ranges from passive-control shade houses that offer some protection from the elements to the same type of active-environmental-control greenhouses used in the United States and Canada.

California and Florida produced 81 percent of U.S. field-grown round tomatoes in 2019.[40] In Florida and California, most round tomatoes are mature green tomatoes, which are picked while green and ripened with ethylene gas—the plant's natural ripening agent. Mature green tomatoes are firm, slice well, and are preferred by the food service industry, including fast-food restaurants. Other fresh tomatoes—especially those grown in a CEA structure—are vine-ripened, meaning they are picked after turning red on the vine and are more fragile than mature green tomatoes.

In the 2017–19 period, the United States produced an estimated average of 2.8 billion pounds of fresh-market tomatoes of all types, which is down 34 percent from 2000–2002 (table A-9).[41] The production of U.S. fresh-market field tomatoes declined by 53 percent since 2000–2002, including a drop of 40 percent in California, 47 percent in Florida, and 51 percent for the rest of the United States, while the U.S. CEA tomato industry expanded.[42] The availability of CEA tomatoes has reduced the retail market for mature green tomatoes, which are now sold mostly to fast-food restaurants, although one fast-food restaurant plans to switch completely to vine-ripe CEA tomatoes (Malone, 2018).

[40] Numbers are from USDA, AMS' Market News. Round tomatoes are anything not otherwise specified, which in 2019 were cherry, grape-type, and plum-type tomatoes (Roma).

[41] USDA, ERS estimates CEA tomato production since USDA, NASS does not provide data for this type of tomato.

[42] The California average is based on 2017–19 data, the Florida average is based on 2017 and 2019 data (2018 not reported), and the average for the rest of the United States is based on 2017 data since that was the last year data were available.

Table A-9
Fresh-market tomato industry statistics, calendar years 2000–2002 to 2017–19

		Average		Percent change
		2000–2002	2017–19	
Production[1]	Million pounds	4,171	2,756	–34
Imports[2]	Million pounds	1,773	4,046	128
Import share of supply availability (weight)	Percent	30	59	99
Exports[2]	Million pounds	380	180	–53
Export share of supply availability (weight)	Percent	6	3	–59
Per capita availability	Pounds	19.5	20.2	4

[1] Production data for fresh-market field tomatoes from USDA, National Agricultural Statistics Service (NASS) and USDA, Economic Research Service (ERS) adds quantity to account for States not included in USDA, NASS estimates. After 1996 includes USDA, ERS estimates of domestically grown protected culture tomatoes.

[2] Trade includes tomatoes grown under protected culture structures.

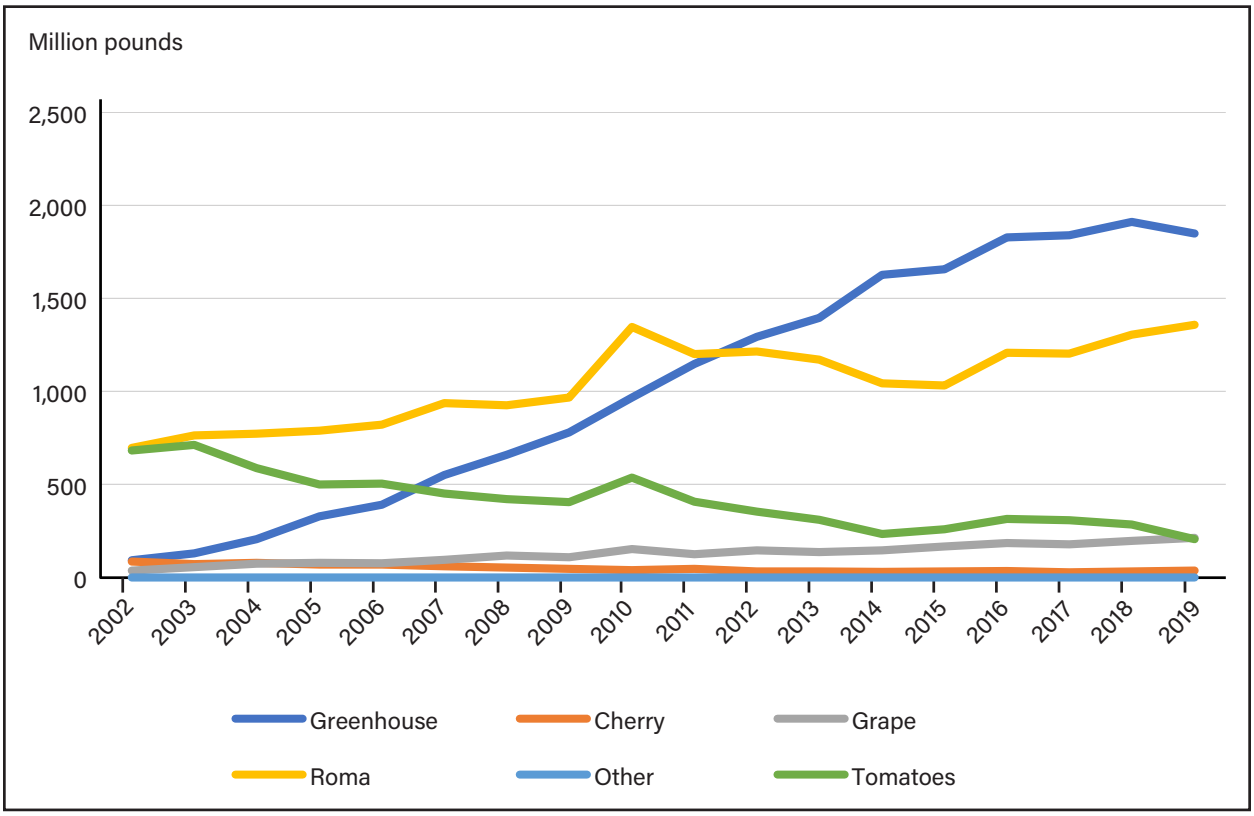
Source: USDA, Economic Research Service calculations.

Imports of all types of fresh-market tomatoes increased 128 percent between 2000–2002 and 2017–19, making imported tomatoes 59 percent of all fresh tomatoes available to U.S. consumers. U.S. tomato exports declined by 53 percent over the same period. Before the growth of Canada's CEA industry, the United States shipped large quantities of fresh-market tomatoes to Canada (Cook and Calvin, 2005). With the decline in field tomatoes and the increase in CEA tomatoes, U.S. per capita availability increased 4 percent.

U.S. fresh-market field tomato production is seasonal. California harvests in summer and early fall, whereas Florida harvests during the winter and spring. Imports—the major source of fresh tomatoes available to U.S. consumers since 2012—peak during the winter months of January through April and drop during the summer months. With the advent of CEA imports, however, there is now less seasonality with substantial, monthly imports from Mexico.

Tomato imports from Mexico grew with the CEA category leading all other types of tomato imports (figure A-9). Field Roma-tomato production in Mexico also increased, but all other types of field tomatoes declined. Mexico still exports small quantities of mature green tomatoes to the United States, but these tomatoes are largely grown in CEA structures, not in open fields.

Figure A-9
Tomato imports from Mexico by type, calendar years 2002–2019[1]



[1] "Cherry," "Grape," "Roma," "Other," and "Tomatoes" are field-grown. "Greenhouse" includes any type of tomato grown in a controlled environment agriculture (CEA) structure.

Source: USDA, Economic Research Service using U.S. Department of Commerce, Bureau of the Census data.

Under the North American Free Trade Agreement (NAFTA), trade frictions between U.S. and Mexican tomato producers came to a head. Florida tomato growers, asserted in 1996 that growers in Mexico were dumping or selling tomatoes in the United States at prices less than their cost of production (Hodges et al., 2019). Later that year, the U.S. Department of Commerce made a preliminary finding that dumping was occurring but—instead of imposing anti-dumping duties on Mexico's tomato imports—Mexico and the United States reached an agreement. The agreement suspended the United States' dumping investigation if producers in Mexico only sold tomatoes to the United States when the U.S. FOB (free-on-board) price is at or above a specified reference price, creating a price floor for U.S.-grown tomatoes. Despite this protection, the U.S. field-tomato industry has continued declining. Under the United State-Mexico-Canada Agreement, conflict over tomatoes has continued (Karst, 2021).

Tomato Labor

The growing and harvest processes are different in California and Florida. Growers in Florida plant indeterminate varieties of tomatoes grown on stakes, which continue to produce fruit until the weather gets too hot, so fields are harvested multiple times. California growers use determinate varieties that grow on bushes without support and mature around the same time, so each field is harvested just once.

Mature green tomato fields in California are largely hand harvested by workers who have two 5-gallon buckets, each holding about 25 pounds of tomatoes (Martin, 2020). The 30-person crew is divided in half, with 15 workers on each side of a gondola that moves slowly through the field. Workers fill two buckets every 2–2.5 minutes and carry them to dumpers on the gondola who credit pickers for their work and dump the full buckets into the gondola.

California field tomato yields in 2019 averaged 36 tons per acre. Workers harvested an average of 125 pounds per hour or 1,000 pounds per 8-hour day or 1 ton every 16 hours. Therefore, harvesting an acre of field tomatoes required 576 hours of labor. With a pack-out rate of 75 percent, net yields are 27 tons or 2,160 boxes (25 pounds each) per acre (Martin, 2020). In 2019 and 2020, harvest workers in California were paid $0.74 per bucket for picking round tomatoes and $0.84 per bucket for picking smaller Roma tomatoes (Martin, 2020).

Data from one California farm labor contractor found workers filled an average of 24 buckets per hour, meaning workers on both sides of the gondola made 12 bucket trips to the bucket dumper, and earned roughly $18 per hour. Local harvest workers averaged fewer than 200 hours in 2019, while H-2A workers averaged 400 hours, so they picked more tomatoes because they worked more hours, not because they picked more buckets per hour (Martin, 2020). H-2A workers are a minority of those harvesting mature green tomatoes in California because most are grown in the San Joaquin Valley, where labor is relatively abundant, but H-2A workers are increasing.

Florida harvest crews often have 24 pickers and 2 dumpers, with 12 pickers covering 6 rows on each side of a truck carrying 1,000-pound bins—or a gondola—that moves through the field. Pickers receive tokens from the dumper for each bucket picked to record their productivity and earnings. Pickers need 1 minute or more to fill a bucket with tomatoes, so filling two buckets, carrying them to the dumper, and returning to pick again requires 2–3 minutes depending on the yield and the picker's proximity to the truck or gondola. During the first harvest, when yields are highest, pickers average 30 buckets per hour or 180 buckets per 6-hour day, but productivity declines on subsequent picks due to lower yields.

Piece-rate wages rise as yields declined. In 2015, piece rates ranged from $0.55–$0.60 per bucket on the first pick to $0.70– $0.75 per bucket for later picks (Guan et al., 2017). Pickers averaged $18–$20 per hour or $108 to $120 per 6-hour day, while dumpers earned $100 per day and drivers $120 per day in 2015. With a pack-out rate of 75 percent, 1 billion pounds of packed tomatoes comes from roughly 1.25 billion pounds of picked tomatoes. This translates into 50 million 25-pound buckets of tomatoes. At an average piece rate of $0.65 per bucket—the rate offered by one Florida grower to H-2A workers in 2020—piece-rate picking costs were $32.5 million (U.S. Department of Labor, 2021b). There are limited data on H-2A employment by commodity, but industry observers believe that most Florida oranges and a rising share of strawberries and vegetables are harvested by H-2A workers.

Alternatives and Outlook

The U.S. mature green tomato industry is in decline and might decline faster if the foodservice industry switched to CEA vine-ripened tomatoes. Imports from Mexico are likely to continue increasing as the U.S. industry shrinks. In the 1960s and 1970s, some California fresh-market tomato growers used a mechanical harvester developed for processing tomatoes to harvest mature green tomatoes, but these growers soon returned to hand harvesting partly because pack-out rates were significantly lower for machine-picked tomatoes. In addition, machine-handled fruit can have fungal decay that appears 1–2 weeks after harvest, shortening the shelf life of machine-harvested tomatoes.

Mechanization in Florida would be even more difficult because tomatoes are staked and picked several times. So a machine could not be used unless Florida growers developed tomato varieties that ripened uniformly without the use of stakes. Furthermore, with production declining, it is unlikely anyone would invest in developing a mechanical harvester for what would be a small market. For example, California has about 25,000 acres of mature green tomatoes and, if machines harvested 1 acre per hour—slightly slower than the machines that harvest processing tomatoes—and they worked 15 hours per day to harvest 15 acres per day, each machine could harvest 1,500 acres over a 100-day harvest season, and 17 machines could harvest the entire crop in California. Such a limited market reduces private sector incentives to tackle the plant breeding and technical challenges of developing harvesting machines that would require new plant varieties and packing systems.

Conclusions

This report investigates growers' adjustments to rising labor costs for several commodities including four labor-intensive fresh fruit and three commodities within the vegetables and melons sector. Growers are faced with rising labor costs. If growers want to continue growing their current crops, they may consider mechanization. Many crops now lack mechanical solutions, and even when the technology is available, growers may be constrained in their ability to use it. Using H-2A labor can serve as a bridge to future mechanization. In some cases, rising imports could lead to lower domestic-grower prices, encouraging growers to adopt labor-saving mechanization—if available—to reduce labor costs. Some growers have switched to less labor-intensive crops, while others have grown their crops abroad where labor costs are lower.

Commodities can be grouped at three points along the easier-to-mechanize and harder-to-mechanize spectrum. Blueberries, raisin grapes, and wine grapes, as well as baby lettuce/leaf lettuce, and romaine for salads are at the easier -to-mechanize end of the spectrum in adjusting to rising labor costs. Baby lettuce/leaf lettuce for salads is already almost completely mechanized. However, harvesting machines pose difficult trade-offs. If blueberries are mechanically picked for the fresh market, more must be discarded because machines harvest immature fruit and damage more fruit than hand pickers. Growers want to sell to the higher priced fresh market, so they prefer to hand pick even if the fruit is eventually processed. Rising imports from lower income countries such as Peru and Mexico increase pressure on U.S. blueberry producers to reduce labor costs, which favors more mechanization despite lower yields of marketable fresh fruit.

Raisin grape and wine grape mechanization requires upfront investments for new varieties as well as strengthened stakes and redesigned trellises so bunches of grapes are easier to mechanically harvest. Turkey has replaced the United States as the world's leading raisin producer, encouraging some U.S. raisin growers to switch to almonds rather than invest in new grape varieties and vineyards amenable to mechanized harvesting. About 80–90 percent of U.S. wine grapes are mechanically harvested, but some vineyards with grapes used for premium wine still rely on hand labor. However, with a third of the wine consumed in the U.S. imported, downward pressure on growers' grape prices increases pressure to reduce labor costs.

Fresh commodities near the harder-to-mechanize end of the spectrum include table grapes, whole heads of lettuce, melons, strawberries, and field tomatoes for the fresh market. Some of these crops show a potential to benefit from advancements in the design of mechanical harvesters, but these advancements are in their early stages. Rising labor costs have prompted the development and diffusion of mechanical aids that increase hand-worker productivity, including conveyor belts that move slowly in front of workers as they harvest lettuce, melons, and strawberries, or robots that carry tubs of table grapes from pickers to collection points for packing. Some growers are hiring more H-2A guest workers, hoping to develop a productive farm workforce that returns year-after-year. Young H-2A guest workers—selected for their high productivity and willingness to work in teams with mechanical aids—could increase harvesting efficiency. Higher worker efficiency could reduce the incentive to mechanize compared with current efficiency levels. Many commodities that are likely to continue to be hand-harvested compete with imports from countries with lower wages in at least part of their season, putting pressure on U.S. growers. For instance, early-season grape production in the United States has declined in the face of imports from Mexico.

The apple industry falls in the middle of the easier-to-mechanize to harder-to-mechanize spectrum. Growers are planting new varieties preferred by consumers in ways that facilitate hand or machine picking, and they are adopting harvest platforms to replace ladders and allow hand workers to pick faster. Apple growers in eastern States have hired guest workers for decades, and Washington apple growers are now hiring H-2A guest workers, who likely pick at least 40 percent of the State's apples. There are several mechanical harvesters in development that use vision systems to locate ripe apples and grasping arms to pick and place them in bins without damage. If these technologies become commercialized, apples could move to the easier-to-mechanize end of the spectrum.

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