Identifying Inefficiencies in California's Grain Supply Chain

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ABSTRACT

The California grain supply chain is widely unresearched because grain is not a top-ten revenue crop for the state. However, Californian grain operations continue to hold and provide value throughout the state. Key stakeholders along the grain supply chain, defined in this study as grain growers, millers, and bakers, have faced challenges that have the potential to be fixed or improved if enough attention is allocated to their experiences. This research situates the state's supply chain with qualitative and quantitative methods and investigates how it could be improved to better support the key stakeholders that provide us with local grain. Most wheat-flour-bread literature focuses solely on quantitative analysis of grain supply chains, mainly through mathematical models and yield efficiency. Through surveys, geospatial modeling, and an expert interview, I explore the geospatial makeup of the existing supply chain, the inefficiencies that key stakeholders experience, and how we can envision an efficient supply chain. Results show that most grain growers in the state operate on a small scale, but infrastructure along the supply chain is built for large-scale systems. Likewise, grain millers and bakers feel that there is an inadequate supply of high-quality, affordable, local grain. All three stakeholders of the supply chain would prefer a more local system. Results reveal the need for infrastructure and cooperation along the supply chain that can support those that uphold it. These findings can impact the creation of new or improved grain infrastructure, increase opportunities for stakeholder connections, and support the need for funding in the grain community or nonprofits.

KEYWORDS

Wheat, whole grain, local, small-scale, sourcing and distribution

INTRODUCTION

California grain history began in 1771 when the first wheat was planted in the San Diego River Valley. Wheat was planted before California's most famous crops, including grape vines and orange groves (Borg 1987). Wheat thrived in the Mediterranean climate and vast fertile land of California. The California Mission System (1769 - 1833), which were settlements created by the Spanish for which Native Americans had to involuntarily inhabit in order to be Christianized and 'educated' in the European ways, reached its peak agricultural production in 1821, consisting of 66% wheat and 20% maize (Borg 1987). From the 1850s and onwards, with the California-born invention of combine harvester-thresher machinery, California wheat farms became larger and more reliant on machinery and animal power, especially compared to the East Coast (Siebert 2003). Wheat farming became a significant part of California's agriculture, especially in the Central Valley. Though it is no longer the state's priority, grain continues to be a heavily impactful and important crop within the expansive agricultural state of California.

One might assume that within this strong agricultural state, a well-established and efficient network of infrastructure would seamlessly connect grain farms to other actors within the supply chain. Yet, California grapples with a surprising issue: the lack of an integrated and comprehensive system of grain facilities (California Grain Campaign 2017). Existing wheat-flour-bread literature points to transportation and distance traveled as a fundamental concern; environmental challenges loom as grains travel across both the state and throughout the country, contributing to increased transportation-related emissions and energy consumption (Stoll 1998, Yousefi-Babadi et al. 2023). Added expenses pile up for both farm owners, who tend to shoulder the burden of transportation costs and reduction of profits, and bakeries, who may experience higher input costs as they either source grains from distant locations (Babcock et al. 1985). The economic consequences of these inefficiencies can undermine the competitiveness and profitability of California's farm owners.

Despite these concerns, very little scholarly research exists on the California grain industry, from the general makeup of the existing facilities to the inefficiencies in its specific supply chain. There exists some research on similar topics around the world, especially found in the Middle East, but academic understanding is lacking when it comes to the California industry. In addition, while most grain supply chain research focuses on creating mathematical models to simulate or understand grain loss and inefficiencies, very few use surveys and Geographic Information System

(GIS) maps to analyze the issue from a visual and social perspective. This knowledge gap hinders the development of effective strategies to address supply chain challenges and emphasizes the importance of shedding light on California's grain distribution network. Likewise, because most research relies on mathematical models and data from afar, there is a lack of human-centered, communicated understanding of grain supply chain players' decision-making processes.

This research thesis aims to fill this knowledge gap, offering potential insights into a more sustainable and efficient future for California's grain distribution network. I will investigate how California's grain mill supply chain and distribution system create environmental inefficiencies. Through GIS, I will understand the geospatial makeup of California's grain supply chain by visualizing the distribution of grain growers and grain mills. I will use buffer analysis on ArcGIS Pro to understand what regions have access to grain mills. I expect that there will be areas of grain growers that do not have access to a grain mill. I also expect that the grain growers who are farthest from sufficient grain mills will have larger inefficiencies. Lastly, through surveys and an expert interview I will investigate what inefficiencies exist in the supply chain, and will explore how an efficient and improved supply chain could be envisioned. I expect that an additional grain mill of large capacity, placed in an area of the state that lacks an adequate grain mill, that is close to a large number of grain growers, will result in an improved grain supply chain.

BACKGROUND

Historical and current perspectives on California grain

The agricultural landscape for grain in California looks quite different than it used to. In 1879, wheat and barley accounted for 75% of the state's cropland while only 5% was taken up by fruits, nuts, vegetables and cotton combined. During peak of grain production in California, grain growers cultivated new varieties of grain, with the Sonora and Club wheats being the most popular (Olmstead and Rhode 2017). However, due to farmers' focus being directed towards mechanization and away from seed stock quality, agricultural techniques, or new varieties, growers became increasingly unhappy with their crops (Siebert 2003). Monocropped land and low soil health exacerbated weed problems and lowered the grain's yield and quality (Olmstead and Rhode 2017). As production systems, irrigation, and land access changed, wheat and barley prevalence decreased from 75% to 26% of cropland harvested by 1929 (Olmstead & Rhode 2017). In addition, wheat began to be competitively grown in the Midwest, causing Californian farmers to turn to other cash crops (Personal Communication, Spiller 2024). Wheat dropped in importance within California's agricultural production, and never rose to the same levels again. Though the amount of grain grown in California has decreased over time, it still holds a great significance for its growers and people along its supply chain. As of 2023, Californian wheat has a production value of $86,017,000, and accounts for a production of 8,338,000 BU. Wheat's production value is higher than a variety of staple products such as corn, grapefruit, apples, beans, and more. During the first year of the Covid-19 pandemic, consumers turned to baking as a source of comfort. This has been upheld even after the pandemic has finished. Furthermore, due to the mass supply chain issues that arose from global shutdowns, increased amounts of consumers began to realize the importance of local food and ingredients (Bracale and Vaccaro 2020). The year 2020 was also an important time for Californian grain growers, bakers and mills.

The California Grain Campaign, founded by a collection of farmers, millers and bakers, is "one of many initiatives across the country with the common goal of taking grains out of the world-wide commodity system and placing them into a regional, sustainable, food system" (California Grain). This campaign aims to push the notion that grain processors that sell food should also play a role in supporting the same area's grain producers. They had a '20% by 2020' campaign that pushed for "California farmer's market organizations to require a minimum of 20% locally grown whole grain in products sold in those markets by 2020" (California Grain). Though this campaign did not end up obtaining its full potential, it highlights the perspectives of key stakeholders along the California grain supply chain and distribution system. Because the state's grain community is not large, it is believed that these perspectives that advocate for increased grain distribution and local grower support do represent the majority. These viewpoints factor into my research as its results will present a clearer picture of the California distribution systems's abilities to meet these stakeholders' desires.

Grain-to-flour processes and existing inefficiencies

Transforming grain from seed to flour is a multistep process. During the farming stage of the process, there is cultivation of seeds, planting and growing, and harvesting (Mesterházy et al.

2020). Next there is processing of the grain materials, which includes cleaning, drying, milling, and storage; this step sometimes involves transportation from the farm to the processing plant (Thakur and Hurburgh 2009). Transportation from mill or storage to distribution centers then occurs, which usually involves packaging and movement to wholesalers, retailers, or import/export centers (Nourbakhsh et al. 2016). Lastly, there is retail sale and consumption. The consumption end could involve individual consumers, restaurants, or bakeries (Mesterházy et al. 2020). From existing literature, there are some key inefficiencies that stand out in the grain supply chain. The main causes of grain loss include mistakes in harvesting practices, lack of adequate storage infrastructure, and poor transportation, handling, and packing techniques (Nourbakhsh et al. 2016).

A prominent source of loss is contamination; because the grain passes through multiple lots during harvesting and processing stages, a contaminated portion of grain that is not caught would enter multiple lots and become untraceable, effectively contaminating almost all if not all lots (Figure 1). In situations like these, all grain must be recalled (Thakur and Hurburgh 2009). This loss impacts all players in the supply chain, as each stage uses energy, time, money and people to pass the grain on to the next stage. To mitigate this massive loss, Thakur and Hurburgh recommend implementing a traceability system that would allow for tracking the source of issues, empowering the actors to trace issues to their source without compromising their whole inventory.

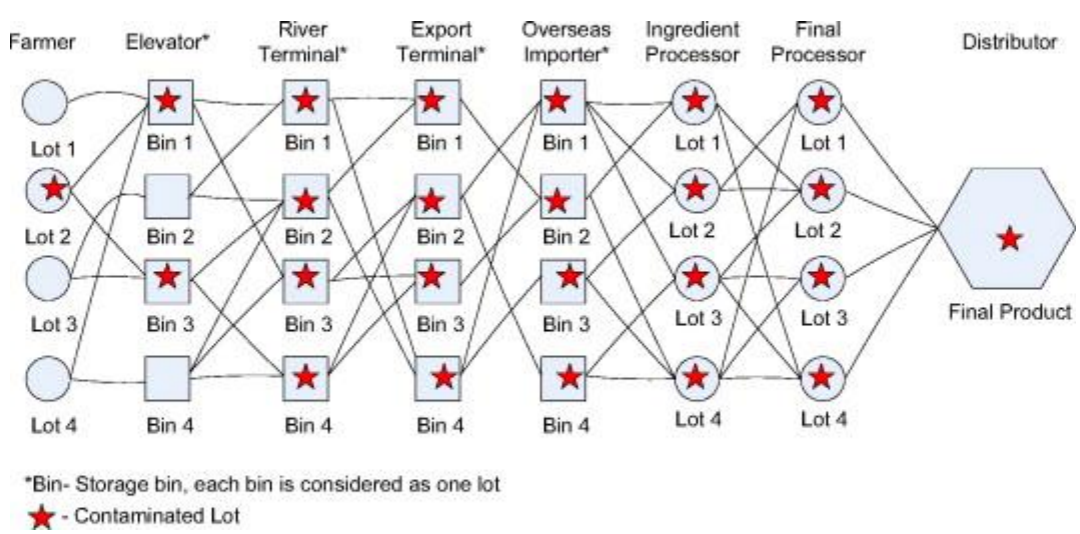

Figure 1. A grain lot aggregation scenario from Thakur and Hurburgh 2009. It illustrates how a contaminated lot can spread throughout the supply chain.

As seen in Mesterházy et al. 2020, the largest source of loss in the grain supply chain comes from the harvest and storage stages, especially for developing countries. In developing countries, almost all harvesting is manual; post-harvest loss accounts for 15% in the field, 13–20% during processing, and 15–25% during storage. In these areas, some of the largest limitations include lack of education about loss, poor infrastructure regarding harvesting and transport, and lack of adequate physical infrastructure. Furthermore, they found that modern storage structures can reduce these losses up to 98%. Thus in the US, ensuring that grain supply chains have modern storage structures would make a drastic difference if they do not already exist.

Similarly, Nourbaksh et al. 2016 found harvesting practices to also be a major source of grain loss. During the harvesting stage, crop losses come from crops being left in the fields, plowed into soil, or destroyed by pests. Uncontrollable climate conditions also have an effect on crops, such as wind, precipitation levels, temperature, and humidity. They found that grain loss is higher when moisture levels are higher, so they recommend beginning the drying process as early as possible in the supply chain; thus the locations of drying facilities is crucial for reducing grain loss and transportation costs. They consider highways and railways as the main forms of transportation. One of their main findings is that the higher the capital cost for pre-processing facilities, the smaller the number of built pre-processing facilities, and the lower percentage of harvested grains that are eventually processed. Thus a main inefficiency to look out for is grain loss during transportation.

Research framework: methodology and literature review

Most existing literature uses mathematical models to understand the supply chain's inefficiencies or areas for potential optimization. In Nourbakhsh et al. 2016, they created a mathematical model that optimizes the number and location of drying facilities, transportation routes, and transportation infrastructure expansion abilities. They mapped out a network of nodes on links to visualize their model and determine the most efficient logistics for grain transportation and infrastructure that would reduce post-harvest loss in the grain supply chain, and minimize monetary costs. Similarly, Apaiah and Hendrix 2005 used a quantitative linear programming model, with a similar objective to minimize the sum of the production and transportation costs. They created this model using sensitivity analysis and a variety of decision variables to shape optimization approaches. As another mathematical example, Mesterházy et al. 2020 created a bi-objective mathematical model with a focus on location and storage to minimize costs. Yousefi-Babadi et al. 2023 also used a mathematical model for optimization purposes.

Some literature focuses on implementing traceability to reduce inefficiencies in the grain supply chain. Thakur and Hurburgh 2009 created a model and framework for implementing an internal traceability system that would track grain exchanges, for the purpose of record keeping and database building, which can lead to building variables for optimization. Sharma et al. 2021 investigated existing traceability networks to create a methodological traceability guidance system that could be used to implement traceability in the near future, for the entire grain supply chain system.

Lastly there are a small amount of research studies that have approached these issues through mixed methods, such as visual logistics mapping with GIS and surveys. Aspects of these studies' strategies are most similar to my research in which I used social science-based surveys, along with GIS for grain supply chain mapping. Bhardwaj et al. 2023 implemented a myriad of techniques: they first conducted a literature review of current bread waste and mitigation strategies, and collected data from retailers, which included factors that went into their decision making. They analyzed this data and created a simulation using a Monte Carlo simulation. Next, they conducted a market survey on retailers to understand sources of bread loss. They coded this information and combined approaches to create a simulation. On the other hand, Yousefi-Babadi et al. 2023 conducted a case study on Iran's grain supply chain, looking specifically at facility relocation using GIS.

Overall, existing research covers two main methods to analyze grain supply chain and its inefficiencies: mathematical modeling, traceability framework-building using data analysis. I used GIS and surveys with the state of California as my region of choice. Mapping allowed me to visualize the supply chain network, specifically for grain growers and mills. Surveys allowed me to connect with retailers and understand their experiences in the supply chains.

METHODS

To conduct my research, I used a mixed method, iterative approach in which each technique informed the others (Figure 2). These methods can be categorized as qualitative, for which I conducted surveys and an expert interview; and quantitative, for which I utilized geospatial analysis.

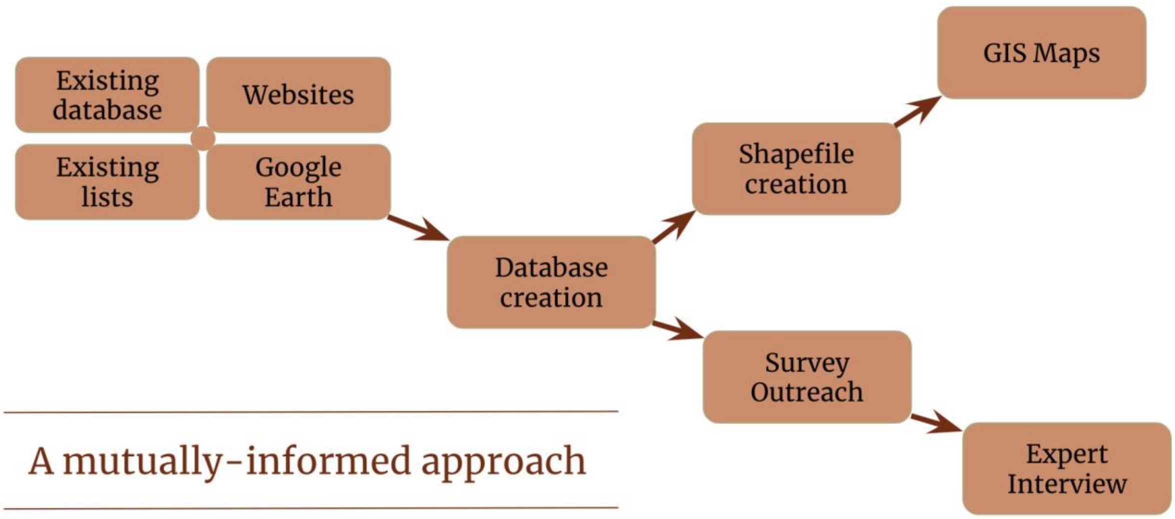

Figure 2: Mixed Methods. The methods I used for this research mutually informed each other. I used four main inputs to create my database, which allowed me to conduct survey outreach and create my GIS maps.

To determine the geospatial locations of the study sites, I first constructed a list of key stakeholders' names (Table 1). This included grain growers, grain mills, and bakeries. An existing up-to-date database with such entities did not already exist, so I had to create it. I created two lists for bakeries, consisting of those that source locally and nonlocally. I curated this list through a combination of methods. I used Google Earth and Google Maps to search for "grain mill", "grain farm" and "bakery". For every search result, I ensured accuracy by checking its name, its physical qualities, and its location on Google Earth. I also used Google to search for its website and other relevant information, such as news articles. I also used existing lists from the Whole Grain Connection, the California Grain Campaign, the Whole Grains Council, and the Daily Grains Map Explorer. These lists came in the form of interactive maps, PDF lists with names and descriptions, or websites. I found two existing databases from the Whole Grain Connection, though they were not up to date. In addition, the lists included some entities that I had already found through Google Earth. However, they were a helpful cross-reference with my database I was making from Google Earth and Maps.

I only added a company to my list if it currently involved wheat (Table 1). For example, a grain grower had to be currently growing wheat to be added to the list. A grain mill had to mill wheat, and a bakery had to make bread or bread products with flour made from wheat. For every company on my list, I added their updated contact information, website, address, and notes, and thus created a database. An example of a note for a grain grower could be "They grow heritage wheat". I found contact information through the company websites or articles about the company. Similarly, I found most addresses from the company's website or articles about the company. I used Google Earth to confirm these addresses. If, for example, an address showed a residential house instead of a farm, I would conduct further investigation to find the true farm's location. When an entity could not be found on Google Earth, I used Yelp or the business's website to compare pictures with Google Earth to determine physical addresses. This database allowed me to create surveys from the company names, websites, and notes, and thus to investigate the main pain points of key stakeholders' experiences in the supply chain. The database also allowed me to create maps from the addresses and company names. This database helped me shape the current geospatial makeup of the grain system.

Table 1. List of key stakeholders in my database. These names represent companies that I included in my GIS map, survey outreach, or both. For their privacy, I do not specify which companies fall into which method categories. In addition, this list does not specify which companies responded to my survey, for privacy reasons.

Grain Growers	Grain Mills	Bakeries
Ancient Agro	Ancient Agro	Beck's Bakery
Bergman Family Farms	Ardent Mills Colton	Bread and Flours
Capay Mills	Ardent Mills San Bernardino	Brickmaiden Breads
Desert Vista Farms	Ardent Mills Stockton Mills	Fournee Bakery
Early Bird Farm	Capay Mills (All CA locations)	Hearth and Stone
Eck Farms	Cook Natural Products	Josey Baker Bread, The Mill
Enney Ranch	Early Bird Farm and Mill	Kantine
Fat Uncle Farms	Giusto's Specialty Foods	La Boulangerie SF
Foggy River Farm	Grain Craft	Manresa Bread
Frog Hollow Farm	Green Valley Grain	Miller's Bakery (Miller's Bake

		House)
Full Belly Farm	Grist & Toll	Morell's Bread
J&T Lohse Farms	Mendocino Grain Project	Ponsford’s Place
Kandarian Organic Farm	Mile High Mill and Grain Co	Schat's Bakery
Kenter Canyon	Miller Milling (All CA locations)	Semifreddi’s
Linda Vista Ranch	Moore's Flour Mill	The Bejkr
Lone willow organic heirlooms	Roan Mills	The Midwife and the Baker
Mile High Mill and Grain Co	Satyam Farms	The Mill
Nuss Farms	Sunnyland Mills	
Open Field Farm	The Midwife and the Baker	
Piedrasassi		
Roan Mills		
Woodhouse Farming and Seed Co		

Exploring Inefficiencies in the Supply Chain

To gain insight into the experience of key stakeholders along the supply chain, I created three surveys with Google Forms and sent them to my database of grain growers, millers, and bakeries. The surveys were very similar but certain questions had altered diction to suit the correct entity. For example, I asked grain growers about how much wheat they grew, and millers about how much wheat they milled each year. Questions centered around their product yield, details on their distribution process, decision-making factors behind sourcing and distribution, local vs non-local preferences, what barriers exist for them, and more.

I sent the surveys to each site via email or contact form. I waited one to three weeks for each site, then followed up if they did not reply. For entities with solely phone numbers, I called them and left a message. I collected survey results and coded them to understand the most popular sentiments from each key stakeholder. I compiled responses into spreadsheets – one for each stakeholder category. For the most relevant survey questions, I coded the responses in order to understand the main themes and takeaways. I grouped similar answers and used color coding and counting to pull out the main themes from these responses (Figure 3).

Distance	Type	Summary	What does local mean to you?
na	mill	na	My mill is the "local" component. I don't use "local" anymore, prefer to highlight "transparency of sourcing and process"
	mill	Few hours	Local is less than a few hours travel from the bakery
	mill	200 miles	within a radius of 200 miles
	mill	Northern CA	Northern California
	mill	Few hours	Imperial Valley or Central Valley
	grower	350 miles	350 mile radius of Esparto
	grower	250 miles	Within 250 miles
	grower	CA	California
	grower	CA	"Super local" = 30 min. drive. "Local" = state of California
	bakeries	One hour	Within 1 hour away is ideal
	bakeries	Northern CA	great question! for us i think it means northern california
	bakeries	CA	In terms of wheat, California grown.
	bakeries	Northern CA	It is a loaded term, but typically would be either San Francisco, Bay Area, the surrounding counties, or perhaps California in entirety. Truly local is more like neighborhood.
	bakeries	One-two hours	Within the Bay Area

What does local mean to you?

Distance	Count	Type Breakdown		
Entire CA	3	1	2	
4-7 hours	4	2	1	1
<4 hours	6	3	2	1

Figure 3: Survey Coding. I assigned colors to each response for distance and stakeholder type. From left to right, this table includes the distance color categories, stakeholder type, the main takeaway from the response, and the response. The smaller table to the right is a summary of the findings.

Geospatial Visualization of Key Stakeholders

Once the database was created, I was also able to create shapefiles for use in ArcGIS Pro. To do this, I searched every location on Google Earth and saved them into the correct category, grain growers or grain mills. I renamed each address to be the company name instead of geospatial coordinates. I added all entities in my database, regardless of whether they replied to my survey or not, and whether I sent the survey to them. There are a small number of entities in my database that I did not reach out to, mainly because they did not have cellular or email contact information available, or because they had in-house production systems. For example, there were some companies that grew, milled, and baked with their own grain. These such entities were not as relevant to my paper, because they did not operate in the state's greater grain supply chain. As a result I did not reach out to all entities that had in-house production systems. For each category in my database, I chose 'select all' and exported the selection as a Keyhole Markup Language (KML) file. I then opened ArcGIS Pro and used the "KML to layer conversion tool". I input the KML file, and the output was a shapefile of the points. I then changed the symbology of the points to have more readable colors, and to delete the automatic labels. Lastly, I increased the size of the points and changed the colors to be as colorblind-friendly as possible. I made the grain growers orange and the grain mills blue. I also added a polygon of the California state, so that the points could be more easily seen in the final map layout. I took note of regions that had clusters of grain growers or mills. I marked areas as potentially inefficient if they did not have access to a grain mill within a local distance.

With the geospatial maps of grain growers and mills that I created, I used buffer analysis to understand what areas might be underserved by grain mills and to visualize the local accessibility of the supply chain. With the ArcGIS Pro buffer analysis tool, I assessed the number of grain growers that were within a distance of 200 miles from each grain mill site. I used the survey responses to the question *"What does local mean to you?"* to develop the average numeric representation of locality. I changed the buffer's color to green, with the circumferences outlined in darker green. These maps allowed me to visualize and understand the spatial arrangement of the supply chain.

RESULTS

Geospatial Visualization of Key Stakeholders

Gaps in grain mill prevalence exist between Southern and Central California (Figure 4). There is a cluster of grain mills in Northern California's Bay Area, and Southern California's Los Angeles area (Figure 4). Meanwhile, grain growers are distributed throughout the state, largely in the Western half (Figure 4).

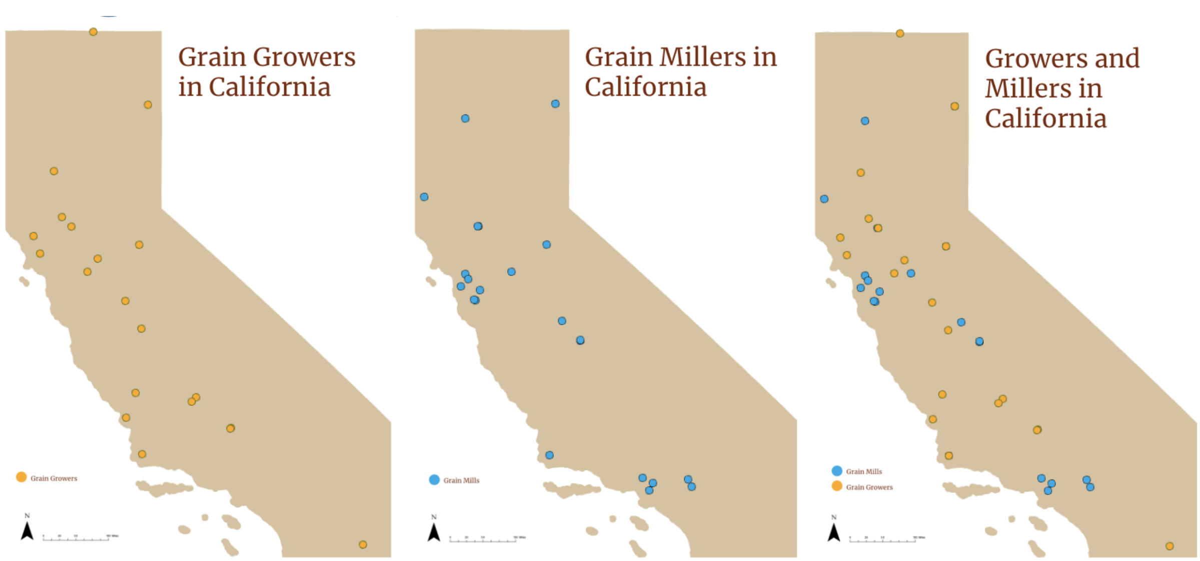

Figure 4: Grain Growers and Grain Mills. Three maps are shown: grain growers, grain mills, and both layers together.

Next, I assessed the regions covered from mills to grain growers within 200-mile buffers. This number was chosen from survey insights. From the survey question *"What does local mean to you?"* I found the most common answer to be less than four hours (Figure 3). To translate this to a numerical unit of distance, I used Google Maps to trial over ten scenarios from stakeholder to stakeholder (farm to mill, for example). This led me to a numerical number of 200 miles to represent the prominent definition of local.

I found that the entire state of California is covered by the 200-mile buffers from grain mills (Figure 5). The Southeastern and Northernmost regions of the state look lighter in color, which means they are more underserved than other regions (Figure 5). However, even these lighter green regions have two grain mills each (Figure 5). Thus the lack of local grain mills concerning geospatial distance is not a major inefficiency in California's grain supply chain, and other sources of inefficiencies need to be explored.

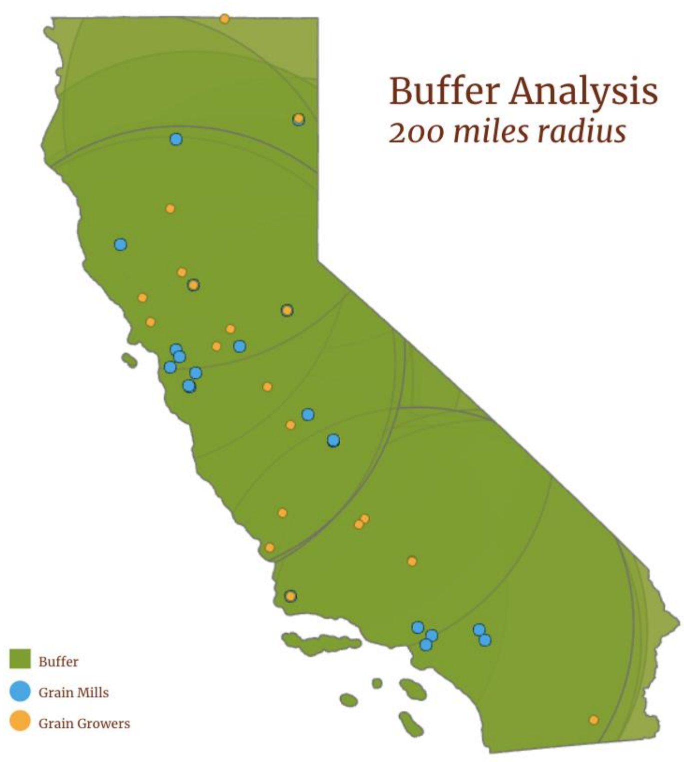

Figure 5. Buffer Analysis. Grain growers and mills overlaid on the buffer. Buffer analysis created circles with 200-mile radii from each grain mill.

Exploring Inefficiencies in the Supply Chain

Surveys and an expert interview allowed me to investigate the inefficiencies that stakeholders experience in the supply chain. Out of those that I sent surveys to, 21% of grain growers, 26% of grain mills, and 29% of bakeries answered the survey questions. As mentioned in my methods section, I was able to code the survey responses and pull out the main themes and takeaways. My takeaways are focused on locality, stakeholders' pain points in the supply chain, the barriers they face, and how the supply chain could be improved.

I found that throughout the three main stakeholders of the supply chain, many entities have in-house production systems, meaning that they grow and mill their grain, or mill and bake their grain (Table 2). There are some who do all three. This means that the inefficiencies in the distribution system are not as directly related to transportation and distance as one might expect.

When it comes to decision-making factors, 'connections and community' and 'cost and quality' are the two main themes established (Table 2). When asked what factors they consider in sourcing or distributing their grain product, cost and quality were the most common themes found. For some stakeholders, the price and quality of the product are their only two concerns (Table 2). This was true especially for grain mills and bakeries. According to my survey results, mills send flour largely to bakeries and distributors both within and outside of California, which means that their flour product needs to be consistent to maintain regular buyers. The consistency of the product relies heavily on the quality of the grain that is sent to the mill. Responses show that grain quality is vital for bakeries, as their customers become accustomed to a certain quality of bread; bakeries must have reliable sources of quality grain to uphold their brand (Table 2). Cost is also a top factor for stakeholders along the supply chain, as they desire to source affordable grain products (Table 2). If grain is too expensive, bakers may look for other sources. On the other hand, the second most important decision-making theme with regard to sourcing and distribution was about relationships in the grain community (Table 2). A common sentiment was that they choose to source or distribute products based on their relationships in the supply chain; furthermore, some interact only with the connections they have built.

Locality was an underlying theme throughout the survey responses. When asked if they had a preference between sourcing and distributing locally vs nonlocally, 64.3% of respondents answered "Yes, I would prefer locally if possible" (Figure 7). 14.3% of respondents voted "No, I do not have a preference" (Figure 7). Zero respondents voted that they would prefer nonlocal. Thus results show that a significant majority prefer dealing with local systems. This positive sentiment is supported further in Table 2, where a stakeholder describes how it is not easy to operate in the local grain economy. However, they choose to support farmers and buyers who live in their region, and a tone of pride can be read. Operating on a local scale is also preferred with regard to the business's benefit: 64.3% of respondents voted that their businesses would benefit if other stakeholders along the supply chain existed closer to them (Figure 8).

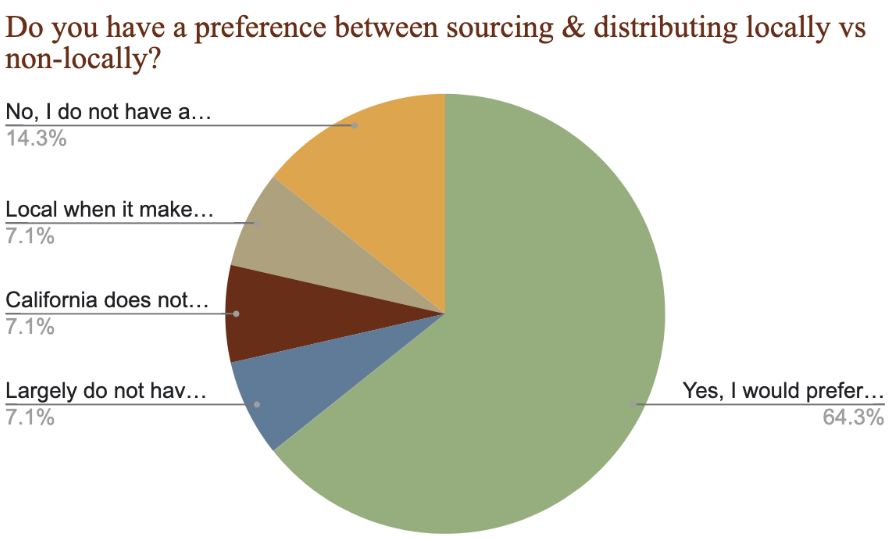

Figure 7. Stakeholders' preferences on locality. In Figure 7, the overwhelming majority of respondents answered "Yes, I would prefer locally if possible". 14.3% of respondents voted "No, I do not have a preference." Zero respondents would prefer nonlocal. The other responses were "Largely do not have a preference. At our size, flour consistency is the most important factor to our customers and that requires large sources of wheat to accomplish year over year. One source means wild inconsistencies in the product", which points to quality and consistency over locality; "California does not grow enough of the wheat varieties that we need to meet our customer's requirements", which points to nonlocal or a mix of both, and "Local when it makes sense. Quality and price over everything", which points to mainly local, though it is not their priority.

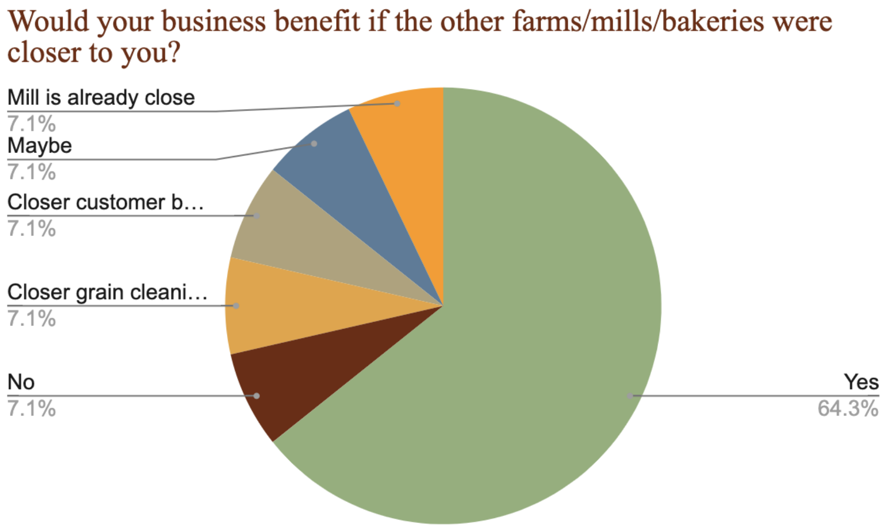

Figure 8. Stakeholders' preference on proximity to other stakeholders. The majority of respondents voted "Yes", that their business would benefit if other stakeholders along the supply chain existed closer to them.

While those participating in local systems seem grateful to do so, the three common concerns of consistency, cost and quality were found with regard to locality (Table 2). Flour from only one local source can point to inconsistencies for bakeries, who rely on large amounts of flour that must have a consistent quality and taste (Table 2). Local grain growers or millers may not be able to supply a sufficient amount of a particular quality of grain that bakers may be searching for (Table 2). Many millers feel that the quality of California wheat insufficiently meets their desires (Table 2). They also say that there is not enough quality supply of the grain varieties that they work with, suggesting that they want more of each type of grain they work with (Table 2).

The largest source of inefficiency that was found from my research was the lack of small-scale infrastructure. The existing grain infrastructure does not support the needs of small-scale grain growers (Table 2). One large source of this problem is grain cleaning facilities; issues with access to grain cleaning were mentioned the most number of times throughout surveys and the interview. Seen in Table 2, a key stakeholder shares that "cleaning [and] bagging facilities for smaller scale growers seems to be a bottleneck. Larger farms get priority. Sometimes the cleaners don't want to bother with small farms" (Table 2). This sentiment around the lack of small-scale infrastructure, especially with regard to grain cleaning facilities, was the most common barrier that stakeholders faced in the grain supply chain.

Table 2. Key findings, themes and quotes. Quotes are pulled from survey responses and the expert interview. Quotes are kept anonymous for grain growers, millers and bakers' privacy protection.

Topic	Themes	Quotes
General California supply chain	In-house production systems	"We're vertically integrated, so [we] produce for in-house use" "We mill our own flour and bake it **in the same location**" "We don't distribute. We use what we mill"
Decision - making factors (sourcing and distributing)	Connections and community	"**Relationship building is what matters**, partnering with farmers and growing practices" "Based on relationships setup and what works." "I've been doing this for 25 years, so [I] have a number of growers I check in with each year. I also use the goldenstategrains.com site for their farm directory, also talk to baker friends."
	Cost and quality	"Cost & Grain Quality" "Price, Wheat Quality… California growers grow a large amount of Feed Wheat that is not good milling quality." "Service, **quality, price**"
Locality	Positive sentiment	"**I'm supporting the local grain economy**. I buy from farmers in my region and sell primarily to people who live in my region. I'm not sure that there are enough people to buy

		our product and could use more customers so that I can make a living. It isn't easy doing it this way!” “As locally as possible for many reasons”
	Concerns (quality, price, consistency)	“Local when it makes sense. Quality and price **over everything**.” “At our size, flour consistency is the most important factor to our customers and that requires large sources of wheat to accomplish year over year. One source means **wild inconsistencies** in the product.” “Once [bakeries] get going with a particular flour, they use huge amounts. The [small] farmer would just disappear in no time at all. And the baker needs consistency and the customer wants consistency.”
Barriers	Grain quality & supply	“**Quality of California wheat crop** for traditional bread flours **is poor** typically and would be very difficult to use by itself for several end consumers.” “**Adequate supply of quality grain** in the varieties we mill. Distribution is difficult. Financing is hard to come by. Regulatory & insurance barriers are significant.”
	Lack of small-scale infrastructure	“Cleaning, bagging facilities for smaller scale growers seems to be a bottleneck. Larger farms get priority. Sometimes the **cleaners don't want to bother with small farms**.” “A complete **lack of small scale** grain growing and handling

		infrastructure from organic seed sources to cleaning to storing to shipping" "...there aren't very many places in California where the grain farmer/miller can send their grain to clean."
Improving the supply chain	Locality	"**More local mills**, awareness of whole grain flours and products, awareness of millets, more youngsters joining the movement" "Storage options closer by" "[An] inefficiency is the lack of local mills. And it needs to be local because whole grain flour, even if it's not wet, doesn't have the several years shelf life that refined flour has."
	Small-scale infrastructure	"More of a small-scale focus. Create infrastructure for different scales of farming and processing." "More farmer owned co-op processors, cleaners and mills." "Small scale would work if we had small scale cleaning, and local cleaning (with local being where the farmers are in that area). It would work if we had a small grower, small cleaner and small mill all within 100 miles."

DISCUSSION

This study visualized the presence of grain growers and millers in the state, and identified the main pain points that grain growers, millers and bakers experience along the grain supply chain.

Most existing research centered around grain loss, in which they found the prominent causes for inefficiencies to include mistakes in harvesting practices, lack of modern storage infrastructure, and poor transportation and handling techniques (Nourbakhsh et al. 2016). In addition, existing literature used mathematical quantitative methods to optimize transportation routes with regard to storage and drying facilities (Nourbakhsh et al. 2016, Mesterházy et al. 2020). My research is among the first of its kind in California to situate the grain industry's needs and inefficiencies through both quantitative and qualitative lenses. The largest sources of inefficiency in California's wheat supply chain are the lack of infrastructure that supports grain growers' needs, and the lack of adequate grain supply to meet millers' and bakers' needs. By hearing directly from three types of key stakeholders, we see that the main inefficiencies are not from transportation itself. This contradicts my expected findings and existing literature, which pointed to shipping vehicles and distances being major points of improvement in the wheat-flour-bread system (Babcock 1985, Yousefi-Babadi et al. 2023). With regard to envisioning a more efficient supply chain, my recommendations are centered around building infrastructure and transforming grain growing communities.

Exploring Inefficiencies in the Supply Chain

All themes from Table 2 can stem from the largest inefficiency being the lack of small scale infrastructure. Understanding that many stakeholders have in-house production systems, we can see that they operate on at least a somewhat local scale. With their own facilities, they can advance through two or more steps of the supply chain on site. However, they still need to send their grain product to other parts of the supply chain, such as grain cleaning, storing, or shipping facilities. To do this, they use the main decision-making factors of connections, community, cost and quality to decide where to source and distribute their grain. Within that, quality and consistency are the most prominent sources of concern. Many millers and bakers feel that the types of wheat grown in the state do not meet their standards in a consistent manner. Bakeries particularly require large amounts of flour, which may not be obtained in a sufficient manner from solely local sources. This can at times prevent them from choosing local grain. They also voiced cost as a potential disadvantage to choosing local grain. However, findings suggest that these concerns - especially cost and supply - can be addressed by improving the accessibility of grain supply chain infrastructure.

Local grain often means that it comes from smaller farms, who may have more expensive prices. This is because "there aren't very many places in California where the grain farmer or miller can send their grain to clean. [The top cleaning facilities] charge a lot of money for that cleaning. And they charge extra if it's below a certain amount. Then the [small] farmer has to charge an astronomical sum for the grain compared to what we are used to" (Personal Communication, Spiller 2024). Small grain growers face difficulties with sending their grain to cleaning facilities because the facilities are not built for small inputs. Grain cleaning facilities remove impurities from the grain, sometimes called 'dockage'. Impurities can include seeds, dust, broken kernels, stones, pellets, and other contaminants (Fleurat-Lessard 2016). Grain cleaning facilities were not included as one of the key stakeholders in my research, as existing literature did not show that they were vital parts of the supply chain; literature argued that the United States grain industry had little financial incentive to clean their grain ((Fleurat-Lessard 2016).

After each grain variety is sent through the system, the facility's machinery must be cleaned out, which requires resource allocation, especially time and money (Personal Communication, Spiller 2024). The facilities are built for large amounts of grain; thus when small amounts of grain are sent through the system, and the same amount of resources are used to clean the machinery, it is inefficient, and capital is lost (Personal Communication, Spiller 2024). As a result, small-scale grain growers experience difficulty sending their product through the grain system. Results from Table 2's "Barriers" section show that stakeholders feel burdened by this issue, voicing how there is a "complete lack of small scale grain growing and handling infrastructure", and sometimes "the cleaners don't want to bother with small farms" (Table 2). The lack of small-scale infrastructure must be addressed.

Envisioning an efficient supply chain

Findings from surveys and an expert interview suggest three main pathways towards improvement. One recommendation is to create small-scale infrastructure throughout the supply chain. There are a large number of small-scale grain growers in the state, and these growers need their grain milled, cleaned, distributed, and stored. The current facilities that exist tend to be oriented towards large-scale growers, and thus hinder small-scale growers' abilities to send their grain throughout these facilities. If small-scale grain cleaning, storing and shipping facilities are built, it could greatly improve their experience in the supply chain.

Another option is for the small-scale growers to expand and become large-scale to better fit into the large-scale facilities. One article found that grain farms in Australia are experiencing a trend in which the farms are expanding, and that some level of larger-scale transformation can lead to profitability (Wells 2017). However, this is less realistic in California, as many grain growers grow heritage wheat or other unique varieties (Personal Communication, Spiller 2024). This points to the next recommendation: grain grower cooperation and consolidation. Findings in Table 2 show that this study's three stakeholders of the supply chain often rely on connections to source and distribute their grain product. Grain growers in the same region could connect with each other and form a cooperative or agreement to grow the same types of wheat, and then send it through large-scale infrastructures as one entity. For example, grain growers in the Bay Area (see Figure 4) could agree to grow the same variety of wheat, and send it to grain mills, cleaning facilities, and storage facilities as one larger entity. An expert in grain shares her recommendation, saying, "Smaller scale can be cured if we get to a stage where the farmers in a region come together and decide that some variety in some area grows well here, then they can all grow it and put it together and sell it at a larger scale" (Personal Communication, Spiller 2024). One study found that farm cooperative membership can lead to increased profitability and quality certifications (Liang et al. 2020). Though there is not much research for grain growers specifically, it is worth attempting.

Limitations

The stakeholders I interacted with along the supply chain were limited to the state of California, so findings cannot be directly applied to other states or regions. In addition, I only assessed grain growers, millers and bakers as the three stakeholders. Grain cleaning facilities and grain storage facilities were not surveyed or contacted. Survey analysis was dependent on grain growers, millers and bakers that responded to my outreach; each of these contacts were found through online means, largely dependent on information on websites. I did not contact stakeholders with outdated contact information or no contact information. Stakeholders only replied through email; those contacted through phone or contact form did not respond to my survey. Thus only stakeholders that use email on electronic devices were represented in this study. Consequently, findings in this paper may not fully encompass the sentiment of all California grain supply chain grain growers, millers and bakers. In addition, my paper was largely focused on wheat, so it cannot be applied to all grains, especially rice, which is not part of the wheat-flour-bread system. Barley and other grains in California operate on smaller scales than wheat, which may also be a confounding factor to the generalizability of this study. In addition, this study cannot be generalized for other crops, as the wheat-flour-bread system is unique, especially in this state. This paper differed greatly from existing research in that it combined geospatial analysis, surveys, and an expert interview, with each method informing the other. My paper cannot be directly compared to other research, as it has not been done in California before this.

Future Directions

My study can act as a stepping stone for grain supply chain social science and mixed-methods research in California. I was able to hear from grain growers, millers, and bakers, but future research should prioritize grain cleaning facilities as an additional stakeholder to contact. Grain storage facilities would also be important to interact with. Since grain cleaning facilities were named as one of the largest sources of concern, future research should incorporate their experiences in the supply chain. Future studies should also conduct geospatial analysis with grain cleaning facilities, growers, and millers. Network analysis in ArcGIS Pro from a grain grower to other parts of the distribution process would be useful as a case study. GIS maps that incorporate the capacities of mills, cleaning facilities, and storage should be created. Studies should create maps that can match the output of grain growers with the capacities of mills and other parts of the supply chain. This way, a study could go beyond locality by investigating the realistic potential of a stakeholder to send their grain product to specific stakeholders in the region. With regard to another top concern from millers and bakers, future research should explore grain quality in the state. Millers stated that a barrier they faced in the supply chain was an adequate supply of quality grain in the varieties they mill. Research should explore the reason for this, and work to define what high quality grain means; understanding if the millers' problem stems more from upholding consistency and amount of grain, or from the quality of the wheat itself, would be beneficial in improving their experiences. Surveys should be included in future studies, to continue hearing directly from those who operate in the grain industry. Grain growers should be asked questions related to my recommendations, namely grain consolidation, the potential to expand, and the development of small-scale infrastructure. This way their willingness, ability, and thoughts on these transformations could be gauged.

Broader Implications

This project has a variety of possible applications. The database I created for this project is the most updated database for grain growers and millers in California to my knowledge. It includes the entity names, their websites, addresses, and contact information. I could add the information I obtained from surveys, which includes but is not limited to their grain product output, mill's desired input capacities, the regions they source from and distribute to, the type of transportation used, and their preferences surrounding locality and improvements in the supply chain. If I input that range of information from the surveys into the database as well, then grain stakeholders could use the database as an aid in finding connections and clients in the grain industry. I conducted these surveys on the condition of anonymity, so I would first need to obtain each entity's approval. While conducting survey outreach, some entities asked if I had potential grain stakeholders I could connect them with; this is in line with a key theme of connection and community in Table 2. By releasing this database, I could potentially contribute to improving the experience of these stakeholders. In addition, this database could lead to more research on California's grain supply chain by making it extremely easier to find and conduct outreach to these stakeholders.

This study could also increase the likelihood of monetary grants being allocated for California's grain industry. Geospatial visualizations in Figure 4 show that the grain industry is prevalent in California. The issues detailed in my study that stakeholders deal with have the potential to be addressed, if more research, funding, and resources can be allocated to their needs. By laying out the pain points that stakeholders face in the grain industry, I hope that they can be addressed. Nonprofits or government organizations may be able to provide political or monetary support for these stakeholders, and could use my findings as a stepping stone for further investigation. In addition, this research points to a need for new or transformed infrastructure, especially small-scale grain cleaning and storage facilities, and more local mills (Table 2).

Government organizations, entrepreneurs, or owners of grain facilities can utilize this demonstrated gap in the existing infrastructure to create a useful new business. Ultimately, I hope that my findings can positively impact the grain industry and improve the experience of its vital stakeholders that provide Californians with fresh grain, flour, and bread.

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