

**Scale-up and Design of Sesame Seed-Based Proteins**

**The Effect of Plant-Based Diet Trends on U.S. Dietary Recommendations**

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By

Isabelle Sowers

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Technical Team Members: Avery Baker, Brett Hogan, and Tayler Newton

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

**ADVISORS**

Rider Foley, Department of Engineering and Society

Eric Anderson, Department of Chemical Engineering

## Introduction

In recent years, climate change has emerged as a pressing issue that demands attention from governments, organizations, and individuals worldwide. Evidence shows that the consequences of climate change have led to a warming of the Earth by 1.90 °F degrees since the industrial revolution (Lindsey & Dahlman, 2023). This warming trend has had far-reaching effects, impacting food sources, instigating natural disasters, and raising numerous ethical dilemmas that demand our immediate attention and action (NOAA, 2021).

As the United States (U.S.) grapples with the impacts of climate change, an increasing number of individuals are actively seeking ways to contribute to help the environment. Research conducted by the Pew Research Center highlights this growing concern, revealing that 83% of U.S. adults are making conscious efforts to reduce the impacts of climate change (Funk, 2016). One notable approach gaining popularity is the transition from a carnivorous to a plant-based diet, with nearly 6% of people in the U.S. now identifying as vegetarian, a significant increase from the 1% who did in 1994 (Visé, 2022). This dietary shift is backed by scientific evidence, showing that plant-based diets can effectively reduce greenhouse gas emissions while also offering significant health benefits (Tuso et al., 2013; Scarborough et al., 2023).

The surge in plant-based meat sales, exemplified by a remarkable \$174 million increase in dollar sales from 2019 to 2022 (Ignaszewski & Pierce, 2023), emphasizes the growing prominence of plant-based diets. This shift not only carries economic implications but also influences the way in which the widespread adoption of plant-based diets has impacted U.S. dietary guidelines. While these guidelines are founded on scientific evidence, they have been susceptible to the influence of corporate interests, particularly within the food industry (Callahan, 2023). Conducting an analysis

of the impact of the popularity of plant-based diets on these guidelines is imperative for gaining deeper insights into the nature of these influences.

A crucial aspect of understanding how the adoption of plant-based diets has impacted U.S. dietary guidelines is considering the broader social implications. This includes assessing the effects of transitioning to plant-based diets on traditional meat producers who derive their livelihoods from the sale of conventional meat products. A rapid shift toward plant-based beef production holds the potential to significantly affect the livelihoods of beef producers (Mason-D'Croz et al., 2022). To evaluate the social impact of the introduction of plant-based meat alternatives, it is crucial to consider the perspectives of all stakeholders involved.

As the adoption of plant-based diets continues to rise, the market for meat alternatives has simultaneously increased in recent years with products derived from soy in especially high demand. There have also been concerns about the environmental impacts of the meat industry, pushing people to try more sustainable diet options (Gerbens-Leenes et al., 2013). Currently, the market faces a shortage of manufacturers capable of delivering such products, and issues pertaining to nutrition, taste, and texture may pose significant obstacles for many individuals considering the transition to plant-based diets, so additional priority will be given to the molecular composition resembling animal tissue (Szenderák et al., 2022).

Industry projections within this commercial space are optimistic, as the plant-based chicken market alone is projected to grow 18.4% in the next 10 years (Choudhury, 2023). Since the market is heavily soy-based, the proposed alternative protein source can be derived through extraction of sesame seed media (Krososky, 2021). Although sesame and soy are now both major food allergens in the U.S. (Califf, 2023) there are limited meat alternatives that are not soy-based, restricting options for people with plant-based diets and a soy allergy. This process has the

additional benefit of generating toasted sesame seed oil, a high value product compared to similar oils such as soybean oil.

### Sesame Plant-Based Protein Process Design

The process can be split into four main blocks: seed oil extraction, seed cake fermentation and lactic acid separation, yeast extract processing, and mixing to create the end protein product (Figure 1). This vertical integration of processes allows for development of a unique fermentation media and maximization of production value. The primary source of profit in this case will most likely stem from the oil extraction process, but innovation of the fermentation of the oil byproduct will result in a protein source that can be used to generate a protein dense food to meet market demands sustainably.

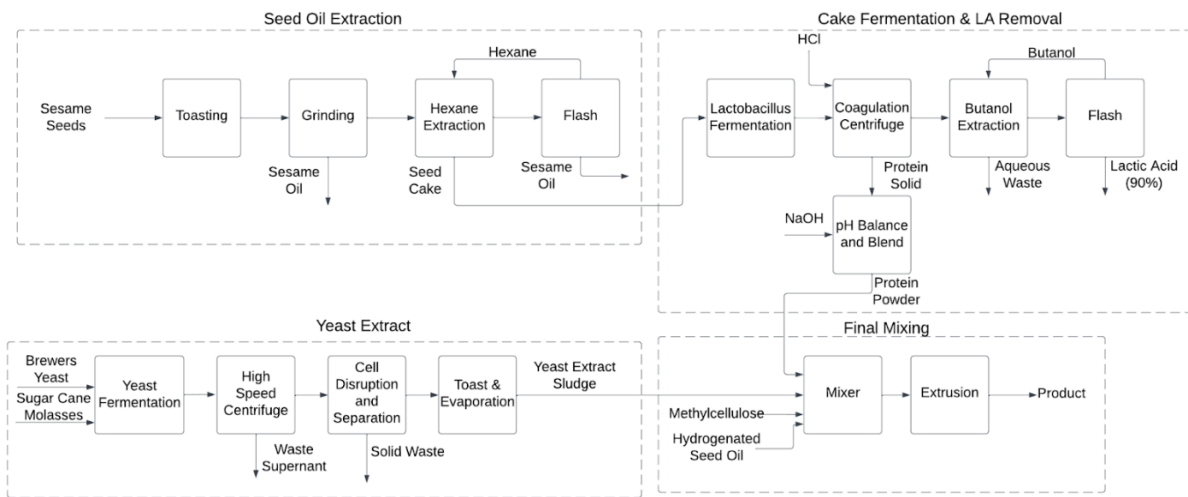


Figure 1. Overview of Production Process

To begin the solvent-based extraction of oil from sesame seeds, the seeds will first be toasted. This pretreatment not only improves the oil yield and shelf life but also enhances the flavor and aroma of the oil. The seeds are ground to release the oil before mechanical pressing and solvent

based extraction (ABC Machinery, n.d.). Most of the experimentation suggests n-hexane as the ideal solvent for oil extraction as it produces the highest yield (Osman et al., 2019). Choosing hexane prevents byproduct formation and simplifies purification. However, the high cost and toxicity of hexane will require a solvent recovery mechanism, most likely through evaporative processes. Both regression models and neural networks exist for prediction of extraction rates, and a method will be chosen that aligns with the precision required for determining average yield. Common yield levels are roughly half of the dried mass of the seeds (Mujtaba et al., 2020).

The leftover seed cake will be used in the protein product but must undergo additional processing to improve flavor and digestibility. Experiments have shown that *Lactobacillus plantarum*, a fermentable bacterium typically found in milk and other fermented food products, can be cultured in seed cake at reasonable timeframes (12-24hrs) (Khalfallah et al., 2022). The results of said fermentation greatly reduce fiber and sugar content, while only resulting in small protein losses in the medium. This is a means of concentrating flavor and nutritional value to produce a higher value-added product.

Following the fermentation, downstream processing is needed to reduce the lactic acid produced, and further improve the consumer experience. A study in consumer reactions to chicken preservation techniques found that the upper limit of consumer preference of lactic acid concentration in chicken products is 1 g/L. (Van der Marel et al., 1989). The expected lactic acid output from fermentation is roughly 6 g/L so extraction will be needed to reduce this value (Khalfallah et al., 2022). A summary of lactic acid retrieval methods recommended extraction as the most scalable option (Li et al., 2021). Optimization of this procedure involves low pH which will coagulate most of the protein (80%) and a centrifuge operation before extraction with butanol (Kumar et al., 2020). Lactic acid is a feedstock for other chemical production, and so the extracted

lactic acid could be sold as a side product. The polar components of the supernatant are likely to be disposed of as a waste stream due to butanol contamination.

To enhance the flavor of the protein product, yeast extract will be added to the fermented sesame product to enhance the savory or “umami” flavor more similar to traditional meats (Tomé, 2021). To create yeast extract, brewer’s yeast or *Saccharomyces cerevisiae*, a byproduct of beer fermentation, is used as the initial source of yeast. This yeast is subjected to a fermentation process with added sugars to increase the number of yeast cells. Once the culture has reached its desired biomass, the yeast cells are centrifuged to remove the liquid medium. Subsequently, they undergo disruption and separation to eliminate their cell walls and then the resulting solution is toasted and concentrated through evaporation (Tao et al., 2023). In this particular method, sugar cane molasses serves as the carbon source for the yeast, while urea is introduced as the nitrogen source to promote yeast growth (Polyorach et al., 2013).

Fermented sesame cake and yeast extract from the process will be combined with methylcellulose and hydrogenated oil produced elsewhere to form a final plant-based meat product, a chicken simulacrum (Figure 1). Side products from this process include lactic acid and toasted sesame oil that can be sold to increase profits. This project will be completed as part of a two-course capstone project, CHE 4474 and CHE 4476, in a group of 4. The majority of the design work will be completed in CHE 4476. Process modeling and calculations will be completed using AspenPlus, Excel, and Matlab.

While the introduction of an innovative plant-based meat product broadens the array of options available to consumers in the realm of plant-based foods, it's crucial to recognize that its implications extend beyond mere consumer choice. To understand the transition to plant-based meat, it's essential to delve into the impacts on dietary guidelines.

## **Analysis of the Plant-Based Diet**

Star's (1999) concept of infrastructure can be used to understand the connection between technical, human, and social dimensions of the transition to plant-based meats. In Star's paper, she points out nine aspects of infrastructure, one aspect is *links with conventions of practice*, which indicates that infrastructure is shaped by our traditions and customs while also influencing them (Star, 1999). Given that traditional diets in the U.S. have long centered around animal-based meats, with the average person in the U.S. consuming over 200 pounds of meat annually (Knight et al., 2022), meat alternatives have gained popularity within plant-based diets for their seamless integration into American culinary habits. In fact, plant-based foods contributed 1.3% to the total spent on food products in 2022 (Ignaszewski & Pierce, 2023). Therefore, we must examine the plant-based diet transformation through the lens of the traditional meat industry, which may provide insights into why some are reluctant to adopt a plant-based diet.

Another aspect of infrastructure that applies to the plant-based diet transition is *learned as part of membership*. This concept pertains to the development of specific behaviors and inclinations among individuals who belong to a particular infrastructure, while those outside of that infrastructure often encounter challenges when attempting to adopt these tendencies (Star, 1999). Some of the primary motivations for individuals adopting a plant-based diet are health and animal rights advocacy (Hopwood et al., 2020). When someone becomes part of an animal rights organization, they typically receive education about alternative diets as a means of promoting animal welfare (Freeman, 2010). This educational aspect often prompts many individuals to choose plant-based alternatives. Numerous people in the U.S. find it challenging to comprehend why these groups lean towards plant-based diets, particularly considering the reliance on animal-

based meats in American diets. This perspective of observing from the outside serves as a valuable starting point for understanding the trends in diets of Americans while investigating plant-based meat production.

On the other side of this, *learned as a part of membership* can be applied to meat-eaters as well. Take, for example, the food pyramid, which had “meat and bean” as one of its main categories. People in the U.S. have been taught that meat is a primary food group, and that it is important to a healthy diet. As such, U.S. diets have reflected this guidance, and the U.S. continues to be one of the highest consumers of meats in the world, consistently remaining in the top 5 countries for meat consumption per capita (OECD, 2023).

Another facet of infrastructure relevant to the transition to a plant-based diet is its *embeddedness*. According to Star (1999), embeddedness is the quality of infrastructure being deeply intertwined with and housed within other structures, social configurations, and technologies. In respect to plant-based diets and the meat industry, embeddedness can relate to how it is intertwined with the economic system. One primary argument raised in opposition to the shift towards plant-based diets revolves around the potential economic repercussions in the United States, particularly within the agricultural sector. Given that this transition is anticipated to reduce beef production, the study delved into the broader implications for the beef industry. The findings indicated a decrease in employment within the agricultural and food manufacturing sectors, while concurrently showing an uptick in employment within crop production (Mason-D’Croz et al. 2022).



## Research Question & Methods

A focal point in the transition to plant-based diets centers on dietary health. This raises the crucial question: How has the growth of plant-based diets influenced U.S. dietary guidelines? Since 1980, the United States Department of Agriculture (USDA) has periodically issued guidelines that advise on healthy dietary choices (Previous Dietary Guidelines, 2021). Grasping the impact of the popularity of plant-based diets on these guidelines is crucial for our understanding of evolving dietary trends.

To assess this impact, a comprehensive review of USDA guidelines since 1980 will be conducted, employing thematic coding to discern shifts in perspectives. This analysis will encompass quantitative methods, including keyword frequency analysis (e.g., "meat" and "plant") alongside thematic coding, facilitating the assessment of the USDA's evolving stance on plant-based diets over the years. By correlating these findings with the surge in plant-based diet trends, the goal is to gauge the level of acceptance of such dietary choices in the United States.

Additionally, the investigation will involve an evaluation of physician-recommended diets. A review of journal articles published in the American Journal of Clinical Nutrition (AJCN) from 2000 to the present, focusing on plant-based dietary recommendations from medical professionals, will give valuable insights into the evolution of the medical community's viewpoint on plant-based diets. To execute this, a search will be conducted within AJCN for the terms "plant-based" or "vegetarian," and the abstracts of these articles will undergo a similar analysis as the USDA guidance, including keyword frequency and thematic coding. Star's infrastructure concepts will be applied to this thematic coding, with a focus on aligning themes to the three concepts of infrastructure mentioned previously: links with conventions of practice, learned as part of membership, and embeddedness.

## **Conclusion**

This research aims to provide a thorough comprehension of how plant-based diets are influencing national dietary guidelines and shaping the advice provided by healthcare professionals. This contributes to a comprehensive discourse on dietary choices and their effects on public health. By using Star's concept of infrastructure, a thorough analysis of the food industry and its impact on dietary guidelines can be conducted.

Furthermore, as the number of individuals transitioning to a plant-based diet continues to grow, there is a need to address the demand for plant-based meat alternatives. To address this issue, the development of a novel product, a chicken analogue derived from sesame seeds, will be conducted. This project aims to provide a solution for those seeking plant-based alternatives while accommodating dietary restrictions, expanding the options available within the plant-based food landscape.

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