Good Food Institute

Plant Protein Primer

EXPLORING THE LANDSCAPE OF PLANT PROTEIN SOURCES FOR APPLICATIONS IN PLANT-BASED MEAT, EGGS, AND DAIRY

The Good Food Institute

GFI is a 501(c)(3)nonprofit developing the roadmap for a sustainable, secure, and just protein supply. We focus on three key areas of work:

Science and Technology
Advancing foundational, open-access research in alternative proteins and creating a thriving research and training ecosystem around these game-changing fields.

Corporate Engagement
Partnering with companies and investors across the globe to drive investment, accelerate innovation, and scale the supply chain—all faster than market forces alone would allow.

Policy
Advocating for fair policy and public research funding for alternative proteins.

GFI officially earned GuideStar's 2019 and 2020 Platinum Seal of Transparency—obtained by less than 1% of nonprofits—reflecting our commitment to maximum impact, efficiency, and inclusion.

We work as a force multiplier, bringing the expertise of our departments to the rest of the world.

United States
Brazil
India
Europe
Asia Pacific
Israel

100+ staff in 6 regions

How will we feed 10 billion people by 2050?

Sustainably

Industrialized animal agriculture is in the top **2-3 most significant contributors** to the world's most pressing environmental issues such as water use, air pollution, and loss of biodiversity.

Industrialized animal ag is responsible for **14.5% of greenhouse gas emissions—**a higher share than the entire transport sector.

Source: United Nations, Livestock's Long Shadow (report)

Efficiently

It takes **nine calories** of food fed to a chicken to produce **one calorie** of meat.

75% of agricultural land is used for raising and feeding livestock yet only provides **1/3** of the global protein supply.

Sources: World Resources Institute (calorie formula); UN FAO (land use)

Safely

Animals in the United States **consume more than 2x** as many medically important antibiotics as humans do.

Based on current trends, medical experts expect **10 million annual deaths** from antimicrobial resistance (AMR) in 2050, a 14-fold increase over current deaths.

Sources: FDA (animal-consumed antibiotics); IMS Health (human-consumed antibiotics); United Nations IAGC (AMR)

GFI’s approach

The Challenge

Current meat, egg, and dairy production is unsustainable and inefficient. It is a key driver of climate change, environmental degradation, and antibiotic resistance.

GFI’s Solution: Accelerating alternative proteins

We can create meat, eggs, and dairy more sustainably and efficiently by making them from plants, cultivating them directly from cells, or producing them by fermentation.

Instead of asking consumers to give up the foods they love, GFI is accelerating the transition to alternative proteins by helping companies make products that are **delicious**, **affordable** and **accessible**.

About this resource

With consumer demand of plant-based products continuing to grow rapidly, more plant protein sources are being explored for applications in plant-based meat, egg, and dairy products. To support the production of products that meet consumer sensory and price requirements, the **Plant Protein Primer** consolidates information on plant protein nutrition, functionality, price, availability and sourcing, other key metrics.

Contents include:

- A basic overview of plant proteins, processing, and choice parameters.
- Profiles of 19 plant protein sources, including a summary comparing these sources on nutrition, functionality, price, flavor, and sourcing.
- A quick glance at 25 additional plant protein sources.
- Strategies for combining different plant proteins.
- Consumer perceptions of plant proteins.
- An overview of processing plant proteins, including production profiles for major product categories.
- Glossary and FAQs.

Plant protein basics

Choice parameters

There are many considerations when choosing the optimum plant protein ingredient, including:

- Protein content & quality
- Nutrition & claims
- Allergenicity, intolerance
- Consumer perception
- Source (geographic, commercial)
- Historical use
- Certifications
- Availability
- Safety
- Regulatory
- Functionality
- Familiarity with use
- Cost
- Aroma, flavor, texture, mouthfeel, color

Intro to protein

Proteins are polymers of amino acids.

The many protein types differ by size, shape, composition, biofunction, behavior in food...

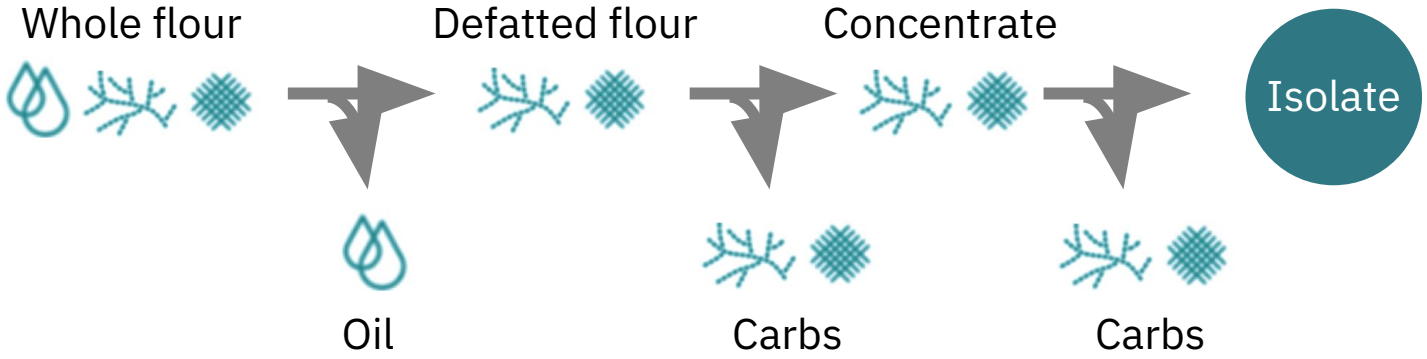
Each plant species has a unique composition of protein types.

Plants also contain non-protein components including starch, fiber, and oil.

Protein processing

Commercial proteins are complex mixtures—properties depend on source and process.

Proteins are often **extracted** to improve their properties.

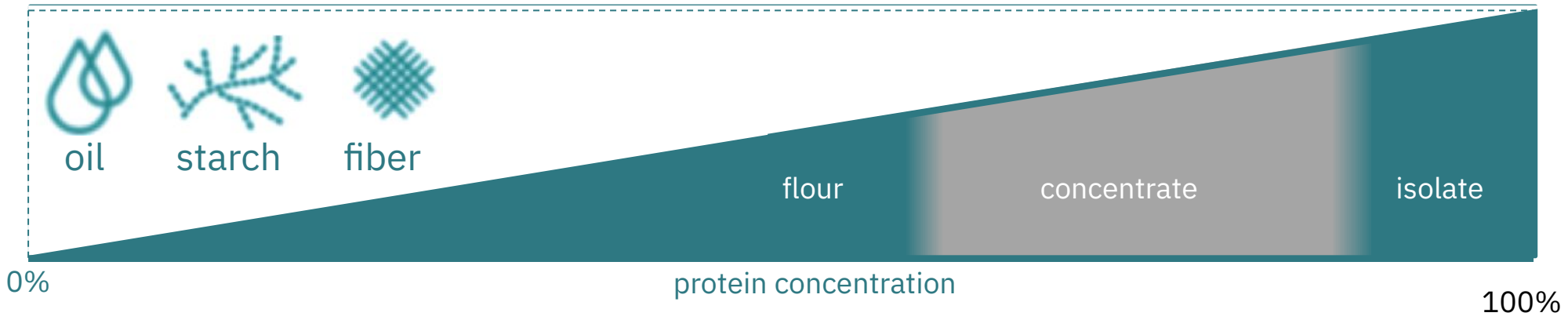


Extraction methods can influence:

- Protein types recovered
- Properties
- Yield

Processing can also influence protein functionality via **denaturation**, **hydrolysis**, **modification**, and **cross-linking**.

Protein extraction



Reduce

- extrusion die slip
- starch texture
- fiber mouthfeel
- antinutritional components

Enhance

- protein gel strength (less network disruption)
- formulation flexibility
- protein nutrient density
- digestive tolerance

Challenges

- maintaining functionality
- cost
- natural perception

Functionality

Proteins are often expected to have useful attributes:

- Dispersibility
- Solubility
- Viscosity
- Gelation
- Emulsification
- Foaming
- Water holding
- Oil holding

These functions may be dependent on:

- Solvent (e.g. pH, salt, Aw)
- Temperature
- Time
- Pressure
- Shear
- Concentration

Plant protein profiles

How to explore the plant protein profiles

The following plant protein profiles represent the most widely available sources. Each of the profiles contains a color-coded comparison on select metrics, and details about **sourcing**, **properties**, **nutrition**, **applications**, a breakdown of **dry composition**, and **product examples.** The below key categorizes performance on each metric. Soy, pea, and wheat are featured first as major benchmark proteins, followed by profiles organized by protein type (legume / pulse / oilseed; vegetable / fruit / nut / cereal).

Key: Plant Protein Sources Summary

	Protein Concentration	PDCAAS	Allergen Risk	Commercial Stage	Flavor	Functionality	Cost (/kg protein)	Global Crop Volume (MMT)
Excellent	>30%	>0.8	Usually mild, low pop.	Commodity	Flavorless	Low conc. effect	<$2	>100
Good	20-30%	0.6-0.79	↕	Large	↕	↕	$2-4	10-99
OK	10-20%	0.40-0.59	↕	Small	Acceptable	↕	$5-9	1-9
Low	5-10%	0.20-0.39	↕	Start-up	↕	↕	$10-19	0.1-0.9
Poor	<5%	<0.20	Severe in sig. pop.	R&D	Objectionable	Water insoluble	>$20	<0.1

Plant protein sources summary

Protein	Protein Concentration	PDCAAS	Allergen Risk	Commercial Stage	Flavor	Functionality	Cost (/kg protein)	Global Crop Volume (MMT)
Soy								
Pea								
Wheat								
Canola								
Chickpea								
Fava Bean								
Lentil								
Lupin								
Mung Bean								
Navy Bean								
Peanut								
Sunflower								
Almond								
Corn								
Oat								
Potato								
Quinoa								
Rice								
Sorghum								

Note: For some proteins, certain metrics are not available

Protein source type

Legume / Pulse / Oilseed

- Soy*
- Pea*
- Canola
- Chickpea
- Fava Bean
- Lentil
- Mung Bean
- Navy Bean
- Peanut
- Sunflower

Vegetable / Fruit / Nut / Cereal

- Wheat*
- Almond
- Corn
- Oat
- Potato
- Quinoa
- Rice
- Sorghum

*indicates a major plant protein source used as a benchmark.

Soy

Type: ***Legume / Oilseed***

A gold standard plant protein

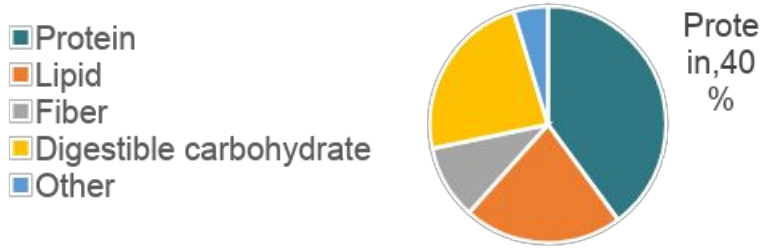
Sourcing

- Grown in Brazil, US, Argentina
- GM: herbicide & insect tolerant
- Poor soil tolerance, fixes nitrogen
- Flour 50–60%, concentrate 65–80%, isolate > 90% protein
- Low consumer acceptance

Nutrition

- PDCAAS 0.84
- Limiting AA: Lys, Met & Cys
- FDA claim: heart disease risk reduction
- Phytoestrogens
- Antinutritive factors: Trypsin inhibitors & hemagglutinin
- Allergenicity: Major

Dry Composition



Properties

- Viscosity & water binding
- Gelation
- Emulsification & foaming
- Flavor-binding
- Earthy & bitter/astringent off-flavors

Applications

- Diverse, e.g., dressing, beverage powder, plant-based creamer, frozen dessert, soup, whipped topping, formula
- Texturized for meat replacement/ extension

PRODUCT EXAMPLES

Pea

Type: ***Legume / Pulse***

Fastest-growing plant protein

Protein Nutrition				●	
Allergenicity			●		
Flavor			●		
Functionality				●	
Cost				●	
Crop Supply			●		

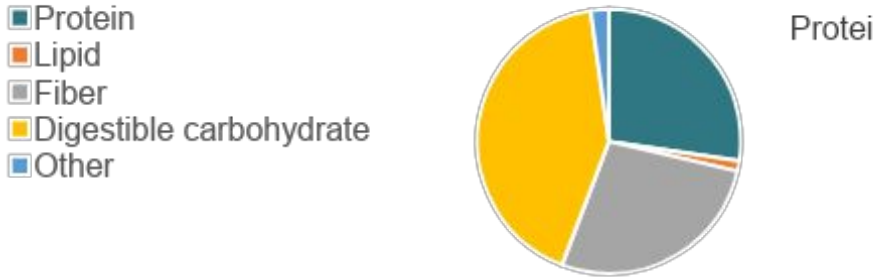
Sourcing

- Mostly dry, whole, yellow peas
- New varieties in northern regions
- Increases soil nutrients, lowers disease
- Available as air classified flour, concentrate, hydrolyzed, texturized
- Cleaner than soy (no hexane extraction)

Nutrition

- PDCAAS 0.64
- Limiting AA: Met & Cys, high Lys
- Fiber, protein, thiamin, folate, P, K
- High BCAA (for muscle repair)
- Antinutritive factors: lectins, trypsin inhibitors, phytic acid
- Allergenicity: Low, possibly due to limited use

Dry Composition



Properties

- Emulsification
- Gelling
- Foaming
- Lower solubility/functionality vs. soy
- Beany flavor

Applications

- Broad applications, e.g., pasta, bakery goods, extruded snacks
- Meat extender/texturizer

PRODUCT EXAMPLES

Wheat

Type: ***Cereal***

Unique functionality and widespread availability contribute to popularity

Protein Nutrition			●		
Allergenicity	●				
Flavor			●		
Functionality					●
Cost					●
Crop Supply					●

Sourcing

- Top 5: China, India, Russia, US, France
- Global trade > sum of all other crops
- Many diseases, pests
- Starch washed from dough vital wheat gluten

Properties

- Elastic dough formation
- Gelling
- Binding

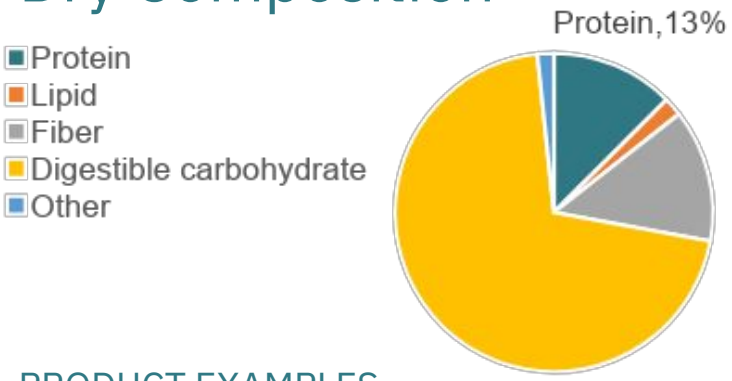
Nutrition

- PDCAAS 0.43
- Limiting AA: Lysine
- Positive health impacts: wheat germ agglutinin (lectin), fiber (b-glucan & arabinoxylan), phenolics, sterols, tocols & vitamins
- Allergenicity: gluten (major allergen)

Applications

- Bakery: dough improver
- Textured for meat extender/ replacer
- Seitan: since 6th century

Dry Composition

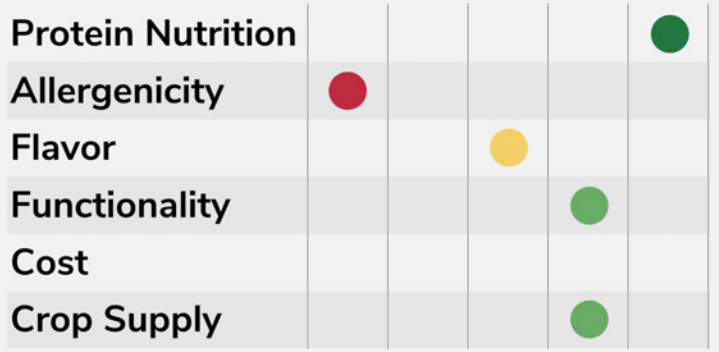


PRODUCT EXAMPLES

Canola

Type: ***Oilseed***

Underutilized & abundant source of high-quality protein with good functionality



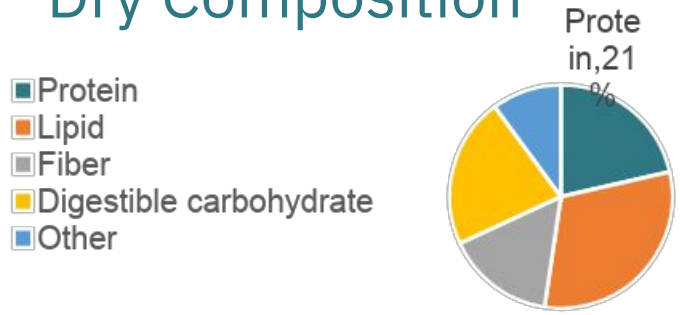
Sourcing

- Protein is abundant oilseed byproduct
- Currently used mainly as animal feed
- Grows in drier areas, soil type tolerant
- Genetically modified crop
- Phenolics need costly removal

Nutrition

- PDCAAS 0.93
- Omega-9 fatty acids
- Allergenicity: labelled as possible allergen in Europe and Canada

Dry Composition



Properties

- Napins foam & cruciferins gel
- Good solubility, water binding, emulsification, foaming, gelation
- Phenolics give dark color & astringency

Applications

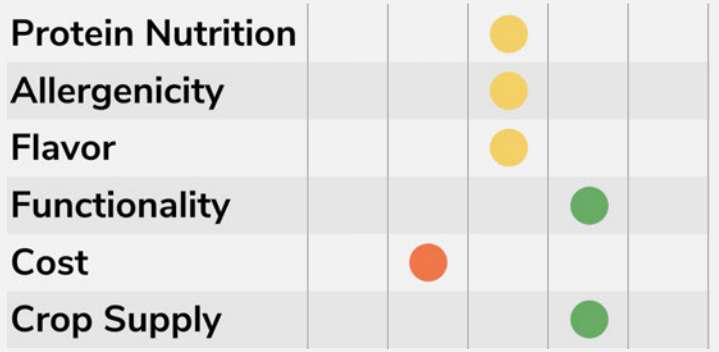
- Sausages
- Mayonnaise (hydrolyzed meal)

PRODUCT EXAMPLES

Chickpea

Type: ***Legume / Pulse***

Abundant familiar legume used as a bulk flour or highly functional protein



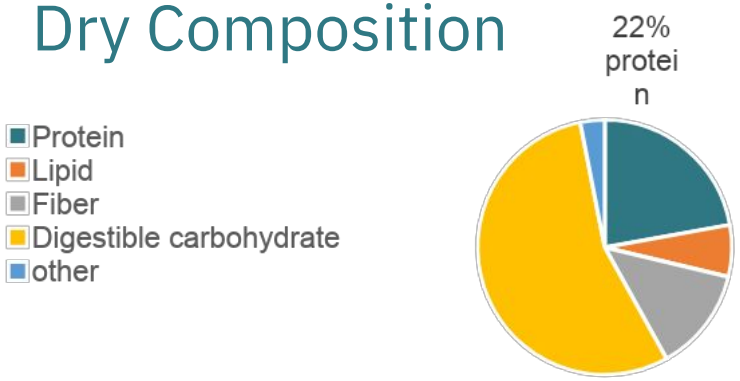
Sourcing

- Major crop in India
- Emerging protein source
- Flour, concentrate, isolates, textured
- Possible pea alternative

Nutrition

- PDCAAS 0.52
- Limiting AA: Cys, Met & Try
- High fiber, folate, iron, phosphorus
- Antinutritional factors
- Allergenicity: regional

Dry Composition



Properties

- High solubility
- Foaming (‘aquafaba’)
- Emulsification
- Flour: gritty mouthfeel
- Characteristic aroma

Applications

- Meat analogs
- PB Dairy
- Mayonnaise
- Pasta
- Bakery

PRODUCT EXAMPLES

Fava Bean

Type: ***Legume / Pulse***

A high protein bean with long history of consumption with good functionality

Protein Nutrition			●		
Allergenicity		●			
Flavor			●		
Functionality			●		
Cost		●			
Crop Supply			●		

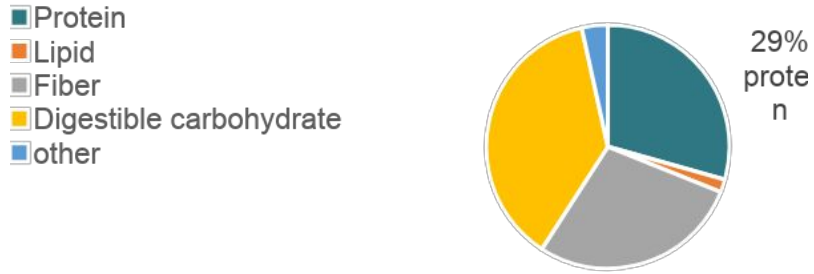
Sourcing

- Grown: W Europe, Australia, China, Ethiopia, Sudan, Egypt
- Hardy: cold, clay, high salinity
- Protein extraction expanding

Nutrition

- PDCAAS 0.47
- Limiting AA: Tyr
- Favism: hemolytic response
- Cook to destroy phytohemagglutinin

Dry Composition



Properties

- Savory flavor
- Gelling
- Water retention
- Emulsifier

Applications

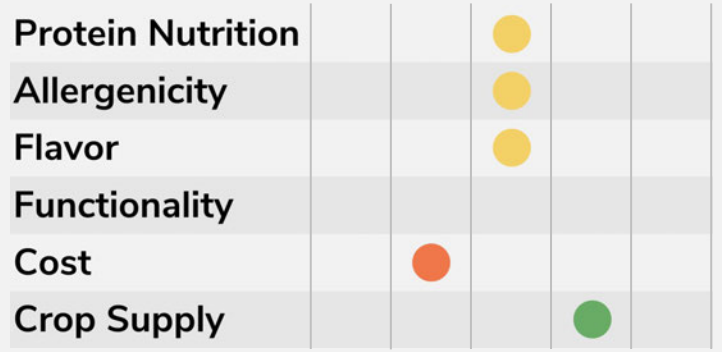
- Plant-based meat
- Plant-based dairy
- Sports/energy drinks
- Snacks & baked goods
- Frozen desserts

PRODUCT EXAMPLES

Lentil

Type: ***Legume / Pulse***

Abundant crop with highly soluble protein



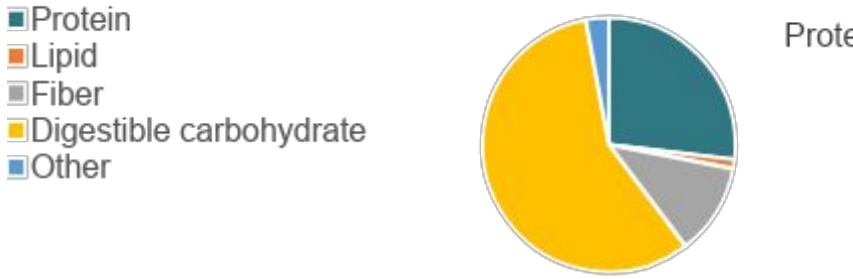
Sourcing

- Oldest known pulse crop, staple in India
- Top 4 growers: Canada, India, USA, Turkey
- Sensitive to flooding

Nutrition

- PDCAAS 0.54
- Limiting AA: low Try, high Lys & Arg
- Protease/amylase inhibitors, lectins, polyphenols
- High in fiber, folate, magnesium, iron
- Allergenicity: important allergen where consumed

Dry Composition



Properties

- High solubility
- Emulsifying & Foaming
- Gelation
- Strong beany flavor

Applications

- Pasta
- Burgers
- Crackers

PRODUCT EXAMPLES

Lupin

Type: ***Legume / Pulse***

A high-concentration protein source with emulsification properties

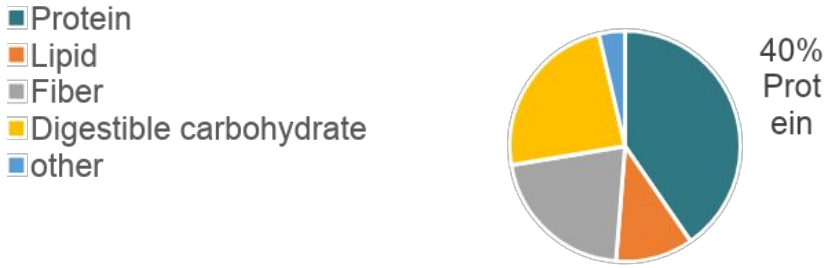
Sourcing

- Grown: Australia, Europe, Russia, Americas
- Limited supply
- No bitter alkaloids in sweet lupins

Nutrition

- PDCAAS 0.4
- Limiting AA: Valine, Met & Cys
- Carotenoids & tocopherols
- Allergenicity: Severe

Dry Composition



Properties

- High solubility
- Emulsification
- Beany & bitter

Applications

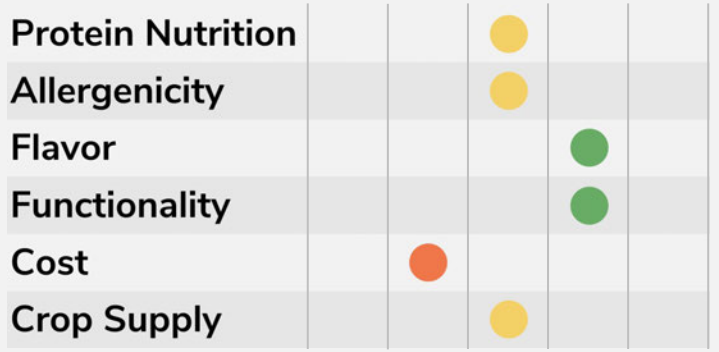
- PB sausages
- Dairy-free milk
- Bakery

PRODUCT EXAMPLES

Mung Bean

Type: ***Legume / Pulse***

Abundant Asian bean with high protein and gelling functionality



Sourcing

- Major crop in E & SE Asia, India
- Low-cost raw material
- Emerging protein extract

Nutrition

- PDCAAS 0.55
- Limiting AA: Met & Cys
- Rich in fiber, potassium, magnesium
- Antinutritional factors

Dry Composition

Properties

- High solubility
- Gelling
- Savory flavor

Applications

- Plant-based meat
- Egg alternatives
- Starch used for noodles, jelly, crepes

PRODUCT EXAMPLES

Navy Bean

Type: ***Legume / Pulse***

A medium-quality protein from US native bean with promising functionality

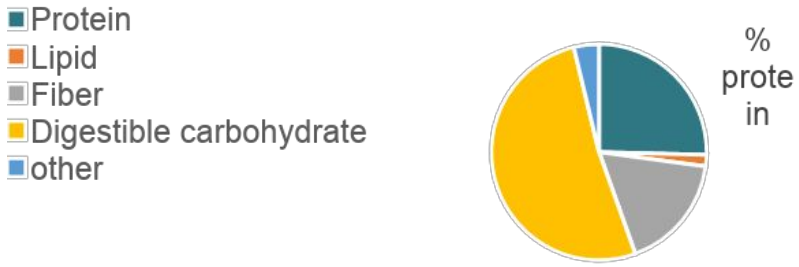
Sourcing

- Native to South & Central America
- Grown in N. Dakota, Michigan, Minnesota
- Protein not commercially extracted

Nutrition

- PDCAAS 0.67
- Limiting AA: Try
- Rich in folate, thiamine, magnesium, iron
- Allergenicity: risk, similar to other legumes

Dry Composition



Properties

- Mild, delicate flavor
- Powdery texture
- Emulsification
- Foaming

Applications

- Baked beans
- Protein: largely unexplored

PRODUCT EXAMPLES

Peanut

Type: ***Legume / Oilseed***

Abundant protein source providing minimally processed high protein flour

Protein Nutrition			●		
Allergenicity	●				
Flavor				●	
Functionality				●	
Cost					
Crop Supply				●	

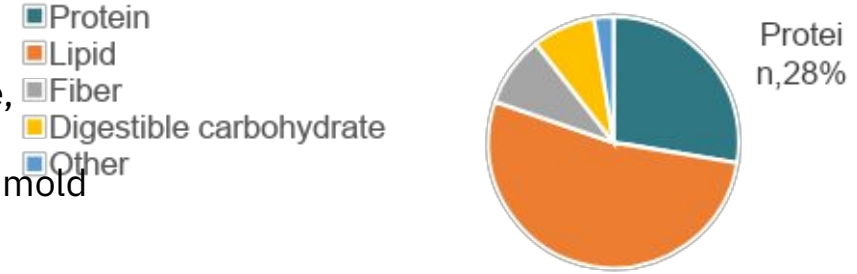
Sourcing

- Grown in China, India, USA, W. Africa
- Byproduct of oil extraction
- Solvent extracts used as feed
- Pressed partially defatted flour is a low intensity product w/ 50% protein

Nutrition

- PDCAAS 0.52
- Limiting AA: Threonine
- Source of vitamins B & E, manganese, magnesium, phosphorus, fiber
- Aflatoxin risk from Aspergillus flavus mold
- Allergenicity: Major (0.6% of U.S.)

Dry Composition



Properties

- Fat binding
- Foaming
- Emulsification
- Gelling
- Extrusion texturization (poss.)

Applications

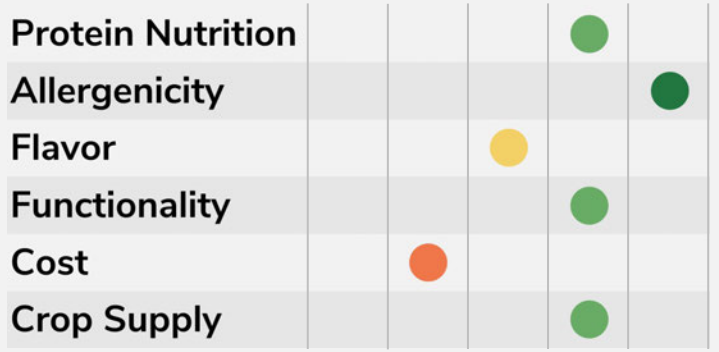
- Whole, roasted & peanut butter
- Extruded crisps
- Baked goods, incl gluten-free
- Traditional sauces e.g., mole negro
- Protein supplement for famine relief

PRODUCT EXAMPLES

Sunflower

Type: ***Oilseed***

An underutilized oilseed byproduct with emulsification functionality



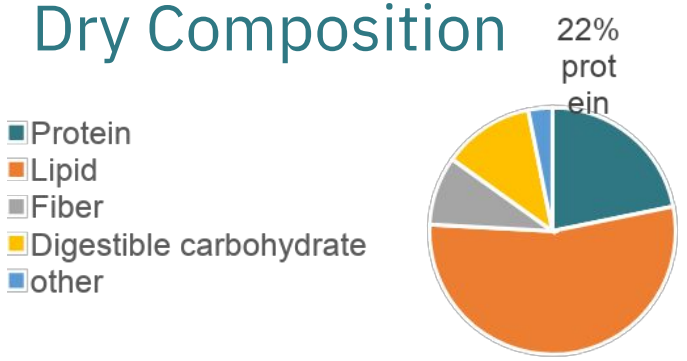
Sourcing

- Abundant oilseed byproduct
- Oil extraction by solvents or pressing
- Process can reduce solubility, functionality
- R&D limited, underdeveloped source

Nutrition

- PDCAAS 0.6
- Limiting AA: Lysine
- Good digestibility (96%)
- Requires chlorogenic acid removal
- Allergenicity: Rare

Dry Composition



Properties

- High solubility
- Emulsification
- Water & fat binding
- Nutty taste

Applications

- Meat analogs
- PB ice cream
- Bakery
- Supplements
- Dressings

PRODUCT EXAMPLES

Almond

Type: ***Nut***

Consumer-friendly with smooth texture and mild taste

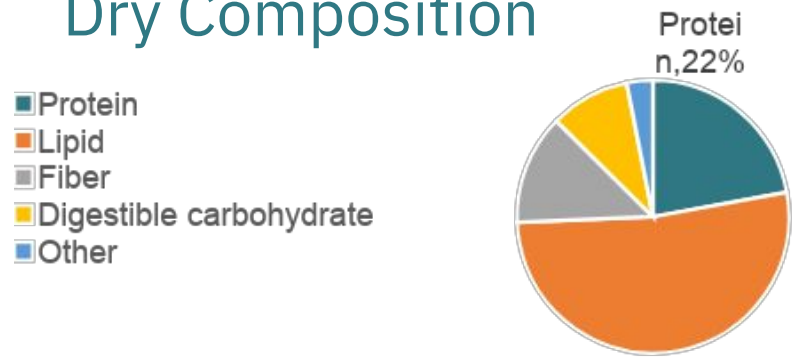
Sourcing

- Grown: USA, Spain, Iran, Morocco, Turkey
- Likes warm, dry summers & mild, wet winters
- Available as 44% protein oil expelled flour
- Good consumer perception

Nutrition

- PDCAAS 0.23
- Limiting AA: Met & Cys
- Source of Mg, P, Mn, Cu, Biotin
- Aflatoxin risk from Aspergillus flavus mold
- Allergenicity: Potential

Dry Composition



Properties

- Pleasant taste
- Smooth mouthfeel
- Thickener
- Emulsifier
- Foaming

Applications

- Powder drink mixes
- Nutrition bars
- Breakfast cereals
- Bakery

PRODUCT EXAMPLES

Corn

Type: ***Cereal***

A major under-utilized low allergenicity protein

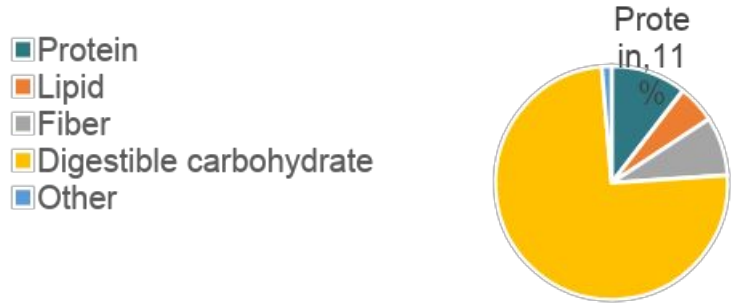
Sourcing

- 92% US corn is GM
- Corn gluten meal has 60-71% protein, byproduct of starch production
- Corn gluten meal = zein + glutelin
- Mainly sold for feed or as zein for technical properties

Nutrition

- PDCAAS 0.37
- Limiting AA: lysine & tryptophan
- Digestibility enhanced by enzyme hydrolysis
- Antinutritive tannins

Dry Composition



Properties

- Zein: Very low solubility, can form fibers, films, enteric coatings

Applications

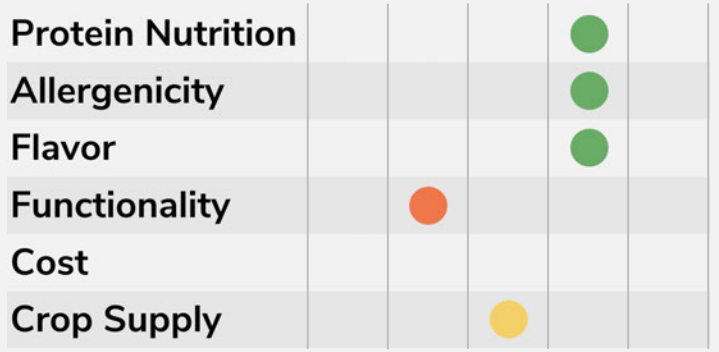
- Zein: encapsulation, edible coatings (nuts, candy), bakery glaze

PRODUCT EXAMPLES

Oat

Type: ***Cereal***

Abundant protein source providing minimally processed high protein flour



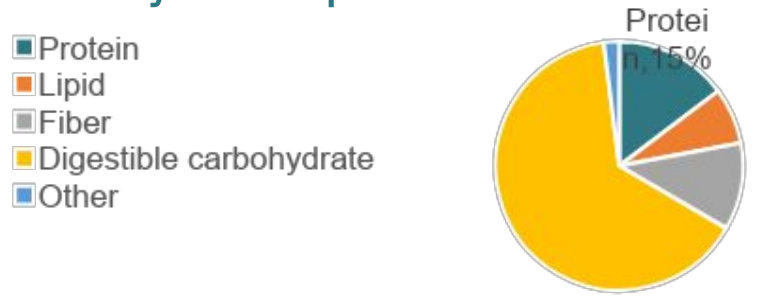
Sourcing

- Well suited to northern regions & organic farming
- High yield
- Tolerant to weather, low fertility soils, disease & weeds

Nutrition

- PDCAAS 0.66
- Limiting AA: Lys, high glutamine
- Beta-glucans & avenanthramides, possible heart health & cholesterol claims
- Gluten-free
- Allergenicity: Low

Dry Composition



Properties

- High stability emulsions
- Some gelling in enzyme hydrolyzed isolates
- Low solubility

Applications

- Oatmeal
- PB dairy
- Baking: bars, breads, snacks
- Beer
- Protein boosts in breakfast cereals and nutritional shakes

PRODUCT EXAMPLES

Potato

Type: ***Vegetable***

A highly-functional, high-quality protein from starch process waste stream.

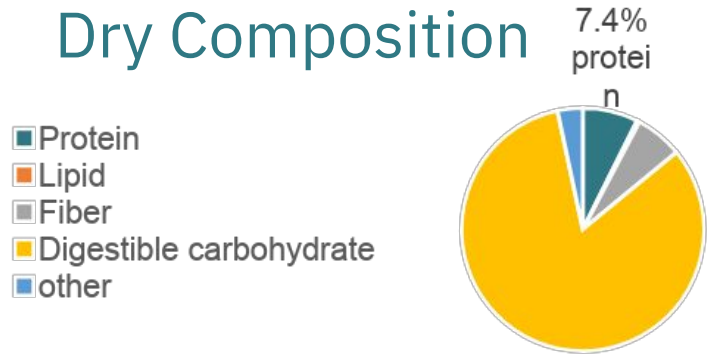
Sourcing

- Mainly produced in Europe
- Limited supply
- Expensive
- Sold as an isolate

Nutrition

- PDCAAS 0.99
- High BCAA & Lysine, potassium, vitamins C & B6
- Patatin: major storage protein
- Allergenicity: Rare

Dry Composition



Properties

- High solubility
- Gelling
- Foaming
- Anti-oxidant
- Metallic flavor

Applications

- Meat analogs
- PB ice cream
- PB cream cheese
- Protein beverages
- Gluten-free foods

PRODUCT EXAMPLES

Quinoa

Type: ***Pseudo-cereal***

A pseudo-grain with high potential for functional, low allergenicity protein

Protein Nutrition				●	
Allergenicity				●	
Flavor			●		
Functionality				●	
Cost		●			
Crop Supply		●			

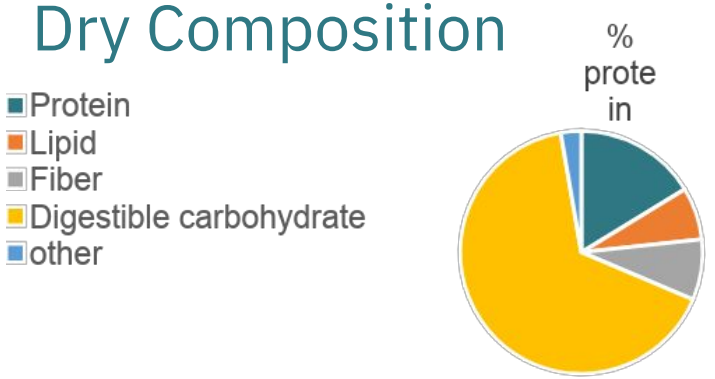
Sourcing

- Grown in Andes, Kenya, India, USA
- Hardy to altitude, salinity, drought, frost, nutrient-poor soils
- Limited but expanding supply
- No commercial protein extraction
- High demand & price

Nutrition

- PDCAAS 0.79
- Limiting AA: Phe & Tyr, high in Lys
- High in manganese, magnesium, phosphorus & vitamins B1, B2, B6, B9
- Allergenicity: Low, possible saponin sensitivity

Dry Composition



Properties

- Foaming
- Emulsification
- Oil and water sorption
- Bitter if saponins remain

Applications

- Consumed as a grain
- Incorporated into products as a flour

PRODUCT EXAMPLES

Rice

Type: ***Cereal***

A byproduct of hydrolyzed starch produced from a globally produced grain

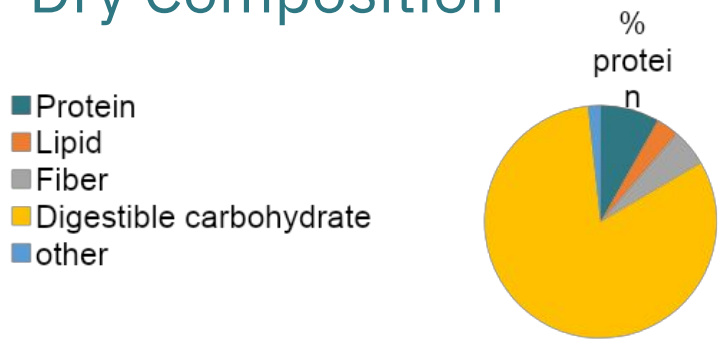
Sourcing

- Grown on all major continents
- Byproduct of syrup production
- Extracted protein is gaining traction

Nutrition

- PDCAAS 0.5
- Limiting AA: Lysine
- Allergenicity: Low

Dry Composition



Properties

- Can be chalky
- Distinctive mild flavor
- Oil retention
- Gelling

Applications

- Meat analogs
- Dairy alternatives
- Bakery

PRODUCT EXAMPLES

Sorghum

Type: ***Cereal***

An under-developed byproduct of starch & ethanol production

Sourcing

- Grown in Nigeria, India, Mexico, USA
- Tolerant to heat, drought, toxic soil, altitude
- Protein extraction not well developed
- Possible byproduct: syrup, starch, ethanol

Properties

- Poor solubility
- Possible barrier material
- Mild, earthy flavor

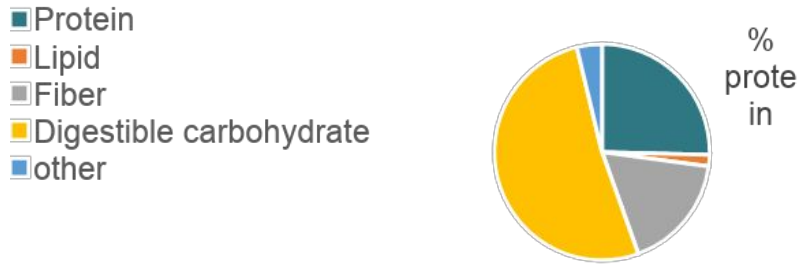
Nutrition

- PDCAAS 0.29
- Limiting AA: Lysine
- Dominant protein: kafirin (insoluble)
- Poor digestibility
- Allergenicity: Rare

Applications

- No known protein uses
- Grain: GF bakery, beer, sweeteners, tortillas

Dry Composition



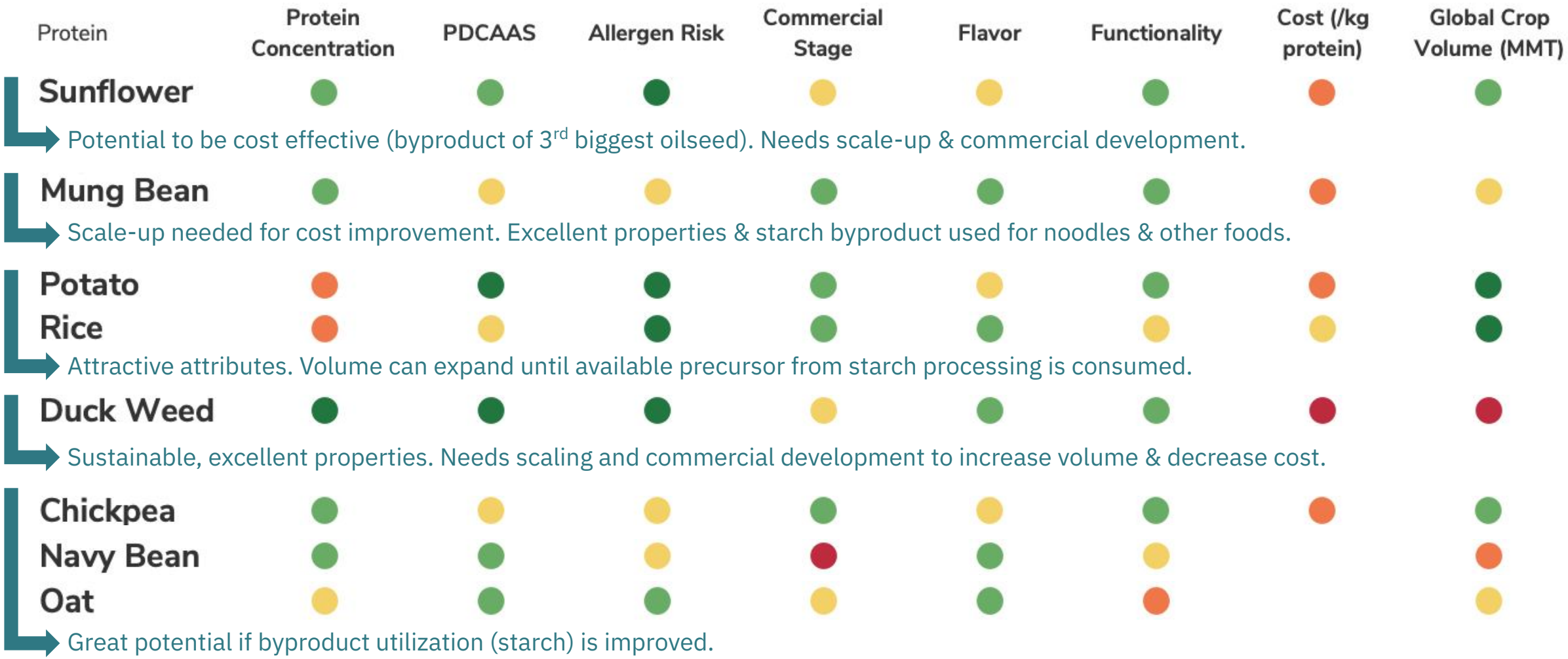
PRODUCT EXAMPLES

Protein sources: Top 10 U.S. plant-based meat retail brands

Brand	Soy	Wheat	Mycoprotein	Pea	Other
Beyond Meat				✓	✓
Boca	✓	✓			
Dr. Praeger's	✓			✓	✓
Field Roast		✓			
Gardein	✓	✓			
Impossible Foods	✓				
Lightlife	✓	✓		✓	
Morningstar	✓	✓			✓
Quorn			✓		
Tofurky	✓	✓			

Note: This deck does not include a detailed profile of mycoprotein.

Plant proteins with growth potential



Alternative plant proteins need a competitive value proposition to bring about growth.
To compete directly with wheat and soy a major question is how well they texturize.

Opportunity highlight: Algae, seaweed, and aquatic plants

Algae, seaweed, and aquatic plants offer a particular portfolio of opportunities as plant protein sources:

- High in protein (e.g. 9-25%)
- Omega-3 fatty acid content
- Scalable (can be grown very efficiently and inexpensively)
- Whole-plant harvesting
- Minimal land use
- Coloration (red seaweeds like dulse turn brown when cooked)

Examples:

Spirulina

Duck Weed

Dulse

Combining plant proteins

Blending two or more different plant proteins can help achieve specific product development goals:

Protein content & quality

Nutrition

Allergenicity & intolerance

Consumer perception

Availability

Functionality

Cost

Aroma, flavor, texture, mouthfeel, color

Examples of synergistic combinations

Note: These are widely used but by no means the only plant protein blends.

Pea + **Potato**

Bricks and mortar

Texturized bulk protein with an emulsifying, heat gelling protein for burgers & other comminuted PB meats

Chickpea + **Rice**

Complementary companions

Increasing PDCAAS by combining a legume (deficient in Cysteine, Methionine & Tyrosine) with a grain (deficient in Lysine)

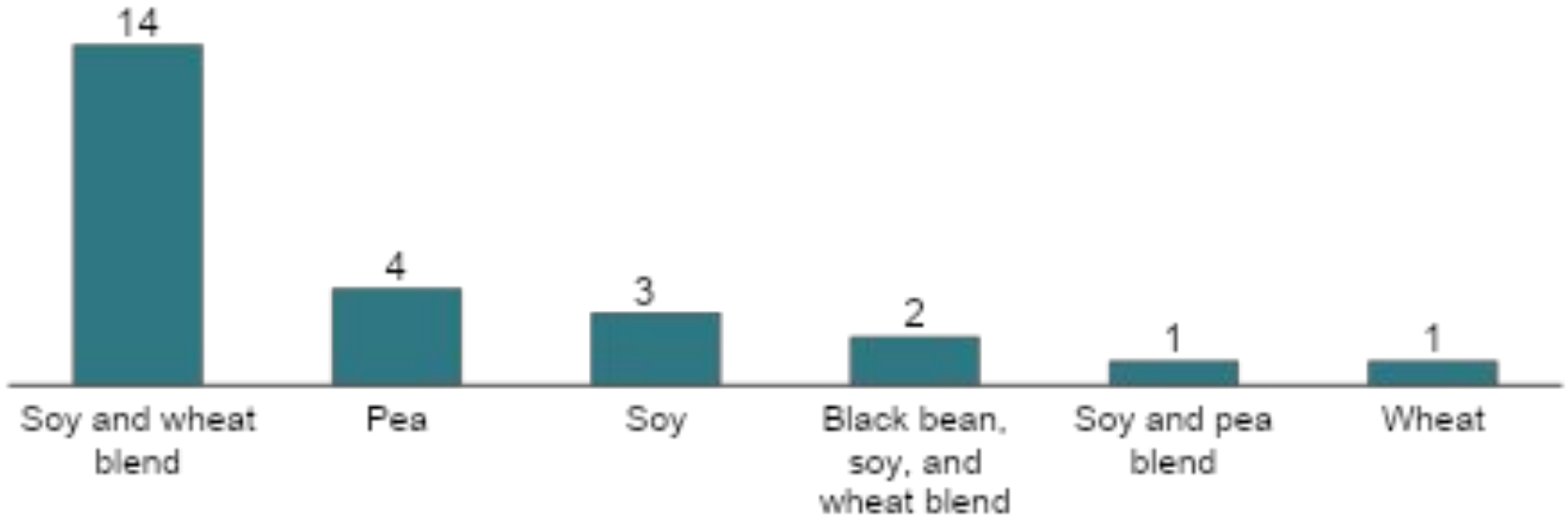
Soy + **Wheat**

Tuning texture

Optimizing meat-like texture for muscle structured PB meat & fish via high moisture extrusion

A soy and wheat blend is featured in 14 of the top 25 plant-based meat products by dollar sales.

Plant protein bases of the top 25 plant-based meat products by dollar sales
2020



Source: SPINSscan Natural Enhanced (proprietary), SPINSscan Conventional Multi Outlet (powered by IRI), 104 weeks ending 12-27-2020

Additional plant proteins

In addition to the plant proteins profiled in the preceding slides, it is valuable to explore additional plant protein sources that offer unique benefits spanning nutrition, taste, functionality, sustainability, crop tolerance, and sourcing issues.

The following slides contain brief profiles on several additional plant protein sources—some of which may not be widely available or are cost prohibitive in the current market. Growth potential for these additional sources may require developments in processing, scaling, and pricing to make them more feasible for wide use.

ADDITIONAL PLANT PROTEINS

Bambara Bean

- Peanut-like legume with 23% protein
- Grown in semi-arid parts of sub-Saharan Africa
- Tolerant to drought, high temperature and marginal soils
- Roasted like peanuts, boiled like beans, ground for prepared foods

Beach Pea

- Peas have 29% protein, mainly globulin
- Nutritionally similar to green pea except higher protein
- Consumed only in local populations where it grows
- Pods contain neurotoxin (ODAP) which causes lathyrism disease

Camelina

- Short-season oilseed cover crop from cabbage family
- Natural pathogen- & insect-resistance, farmed with canola equipment
- Meal from oil production has 40-45% protein
- Protein concentrate: higher emulsification & foam capacity than SPI

Cashew Nut

- Uses significant pesticide and fertilizer
- Cashew nut contains 14-17% protein, rich source of minerals
- Commonly used in foods but not typically extracted as a protein
- Skin of fruit & shell of nut contains urushiol, found in poison ivy

Chia

- Seeds contain 15–25% protein
- Used as food additive, nutritional supplement or base for beverages
- Used in bakery products, cereal, desserts (pudding), egg-substitute/binding agent, shakes/smoothies

ADDITIONAL PLANT PROTEINS

Duck Weed

- Water plant: Minimal land & use and low carbon footprint
- 19-42% of protein (dw), mainly albumins & glutelins (32.1%)
- Oil has low n6/n3 ratio (0.25-0.6)
- High in lutein, zeaxanthin, tocopherols & phytosterols

Dulse

- 35% protein including phycobiliproteins, not commercially extracted
- Very rich in iodine
- Culinary uses, also dried and eaten uncooked

Flax

- Oilseed, contains 20-25% protein, very high in fiber
- Essential fatty acid ALA is known to reduce cholesterol
- Bakery products, binding and soaking agent, cereals, egg-substitute, gluten-free flour mixes, shakes/smoothies

Hemp

- Seed contain 32% protein, PDCAAS 0.66, no protease inhibitor
- Prevents soil erosion and enriches soil with nutrients
- Needs limited pesticides & fungicides, but high H2O & fertilizer
- In US, production is limited, heavily controlled by state governments

Jackfruit

- Easy to grow, resistant to pests, high temperatures & drought
- 5-7% protein in seeds, high calcium, manganese, magnesium, potassium
- Seed flour used in baking, good for thickening and binding

ADDITIONAL PLANT PROTEINS

Lima Bean

- Capable of fixing nitrogen to restore soils
- 19-29 % protein
- Mainly culinary use, Japanese confections
- Presence of anti-nutritional factors (Cyanogenic glucosides)

Mesquite Bean

- Can fix nitrogen, some species considered highly invasive
- 9-20% in bean pods, 26-40% in kernels
- Good source of unsaturated fatty acids, iron, zinc, and phenolics
- Used as nutritional supplement, animal feed, some medicinal use

Millet

- 6th most popular grain globally, similar to sorghum
- Grain has 11% protein, very low PDCAAS (0.24) due to low lysine
- Isolates have good emulsifying and foaming capacity

Mucuna Bean

- Successful cover crop with beans containing 20-29% protein.
- Produces L-DOPA which has various medicinal properties
- Contains various antinutrients.

Penny Cress

- Limited production, mainly experimental
- Oilseed winter cover crop: stabilizes soil & sequesters nutrients
- Seed contains 23% protein, good foaming functionality
- High in potentially toxic glucosinolates and erucic acid

ADDITIONAL PLANT PROTEINS

Pigeon Pea

- Nitrogen fixing & drought tolerant, grown in Asia, Africa & S. America
- 15%-29% protein, high in methionine, lysine, and tryptophan.
- High in B vitamins Mg, P, K, Cu, Mn, Ca and choline

Pongamia

- Ultra-high yield leguminous tree, resilient to poor soil, drought, floods
- Seeds provide protein & oil, possible soy alternative
- Bitter karanjin & pongamol prevent pests but needs removal
- Protein has strong gelling & emulsification function

Potato Bean

- Native to North America & commercially farmed in Japan
- Beans: 25-20% protein (dw), tubers: 16.5% (~3X potato)
- Limited in cysteine & methionine, high in genistein, calcium & iron
- Cultivation challenged by two-year growth cycle

Pumpkin Seed

- Seeds contain 39.25% protein
- High in manganese, magnesium iron copper and zinc, anti-microbial and anti-fungal

Sesame

- Oilseed containing 18-25% protein
- Link of regular consumption with cardiovascular health benefit
- Ground seeds are component in tahini, halva, oil used as a flavoring, whole seeds used as garnish on baked goods

ADDITIONAL PLANT PROTEINS

Spirulina

- Needs no soil & relatively little water – high protein yield per acre
- 43-63% dwb, consumed as a supplement, considered a “superfood”
- Source of gamma linolenic acid, B vits, minerals, chlorophyll, enzymes
- Extensive research as a biofuel

Watermelon Seed

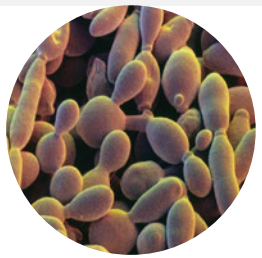
- Seeds contain 16% protein
- Used for oil, animal feed
- Rich source of vitamins, minerals, protein and fat

Wheat Grass

- Kemza® Is a perennial crop that retains topsoil & sequesters carbon
- Grain contains 10-21% protein
- Compared to regular wheat: higher vitamins, minerals, ω3. less gluten, antinutrients

Yam Bean

- Grown in developing countries, several varieties
- Bean contains 20-35% protein
- Mainly used for fodder, minor human food use



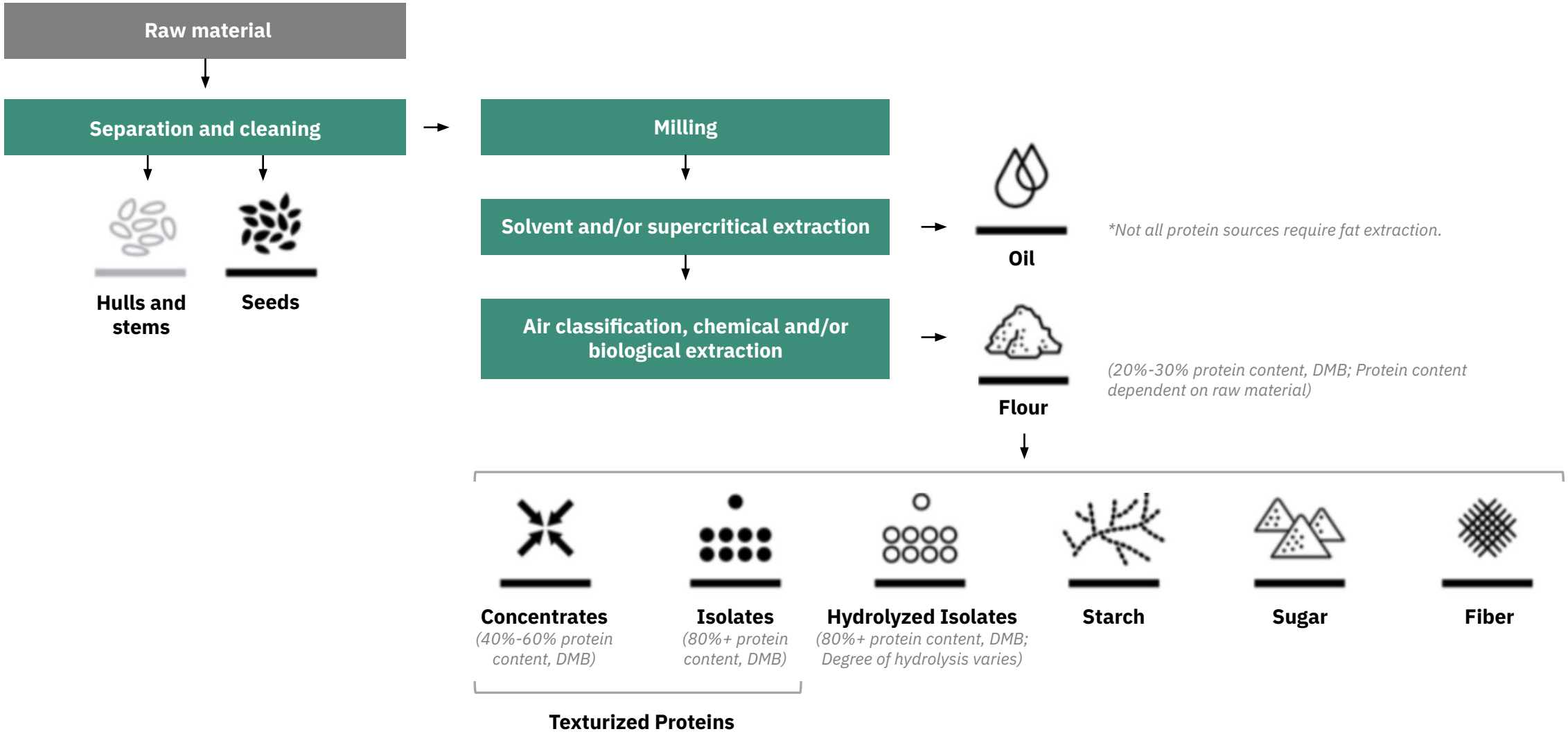
Yeast

- Wastewater from washing has value for crop irrigation
- 40-55% protein, ingredient for flavoring and nutrition
- High content of B vitamins, selenium, zinc, saturated fatty acids
- Supports beneficial gut microflora, can treat Candida albicans infection

Plant protein applications

How do manufacturers take these isolated ingredients from plants and create great- tasting products?

Plant-derived ingredients and processing overview



Functionality

Proteins are often expected to have useful attributes:

- Dispersibility
- Solubility
- Viscosity
- Gelation
- Emulsification
- Foaming
- Water holding
- Oil holding

These functions may be dependent on:

- Solvent (e.g. pH, salt, Aw)
- Temperature
- Time
- Pressure
- Shear
- Concentration

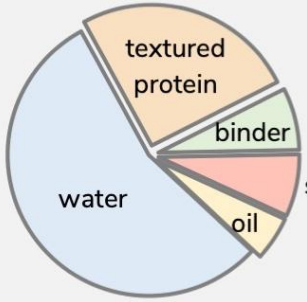
How to explore the production profiles

The following production profiles cover major plant-based product categories—plant-based **meat & fish**, **milk**, **yogurt**, **cheese**, and **eggs**.

Each of the profiles contains details on **composition**, **expectations**, **consumption**, and **areas of opportunity**, as well as an **example process diagram** for a major product in the category alongside an example composition at-a-glance .

Plant-Based Meat & Fish

Process: Plant-Based Burger



seasoning & color

Composition

- Textured base protein, fat, binder, flavor, salt, preservative, color.

Expectation

- Characteristic flavor, texture & appearance
- Provides protein, fat, iron

Consumption

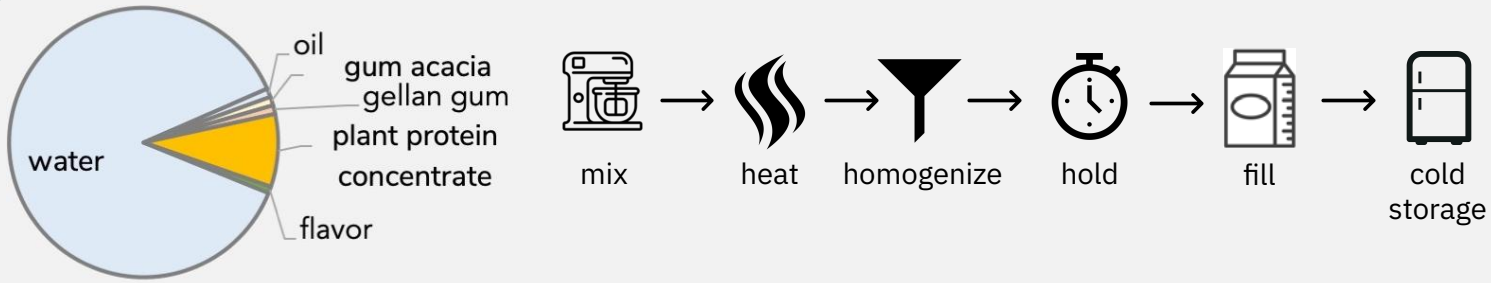
- Center of plate
- **Comminuted**: burgers, sausage, nuggets
- **Intact muscle:** steaks, slices, breasts, wings

Areas of Opportunity

Texture	Intact muscle, fat retention, seafood
Flavor	Base off-flavor, exact matches, subtle flavors (e.g., fish), precursor ingredients
Variety	Goat, lamb, organ meats
Experience	Raw feel, recipe resilience, color change on cooking
Cost	Scale, automation
Health	Alt. proteins, clean label, salt & saturated fat reduction
Authenticity	Shifting from “fake meat” to real food

Plant-Based Milk

Process: Plant-Based Milk



Composition

- Water, base plant protein source, vitamins (antioxidant) minerals (pH reg), salt, sweetener, flavor, texturizer, oil, emulsifier

Expectation

- Smooth, low viscosity, neutral mild dairy flavor & sweetness, white, protein & calcium

Consumption

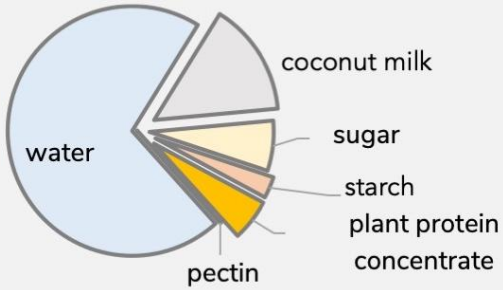
- Cold drink & coffee/tea/cocoa
- Breakfast cereal
- Desserts
- Sauces

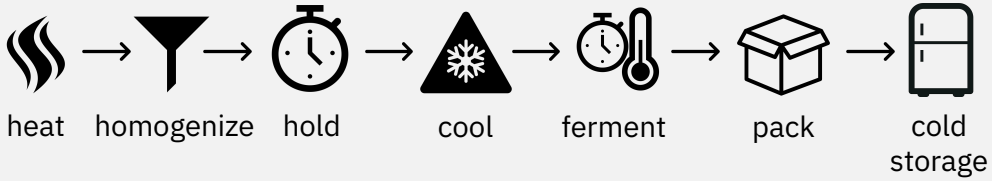
Areas of Opportunity

Functionality	Combining individual products with positive attributes into a single product
Flavor	Dairy flavor, no off-notes
Experience	Creamy texture
Applications	Acid & heat tolerance (barista style)
Cost	Parity
Clean Label	Clean label stabilization
Allergenicity	Allergen-free

Plant-Based Yogurt

Process: Plant-Based Coconut Yogurt





Composition

- Water, base plant protein source, texturizer, culture, often sweetener, pH regulator, vitamins, flavor

Expectation

- Creamy, smooth, viscous weak gel, lactic acid, mildly sweet, white, provides probiotics, protein & calcium

Consumption

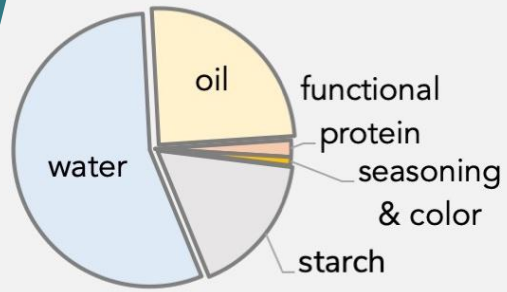
- Cold, sweetened with fruit prep.
- Cold, sauce for savory dish, often w/ spice, cucumber

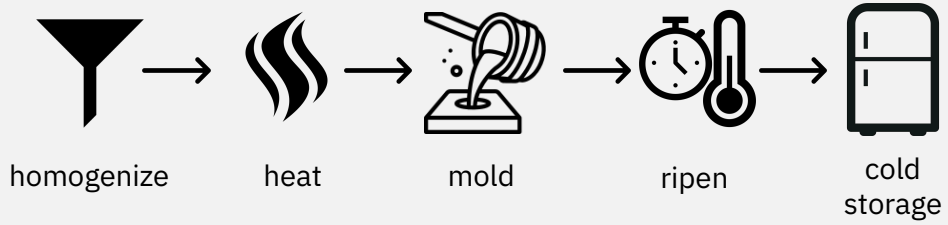
Areas of Opportunity

Functionality	Combining individual products with positive attributes into a single product
Flavor	Creamy flavor, no off-notes
Experience	Creamy non-grainy mouthfeel
Clean Label	Clean label texture & stabilization
Nutrition	Nutritional equivalence
Allergenicity	Allergen-free
Authenticity	Authenticity

Plant-Based Cheese

Process: Starch-Textured Cheese





Composition

- Nut-based: cashews, starch/gums, seasoning,
- Cultured emulsions: coconut oil, starch/gums, seasoning, acid, color, preservatives.

Expectation

- Yellow/white, fatty/creamy, lactic acid, indulgent, provides protein & calcium

Consumption

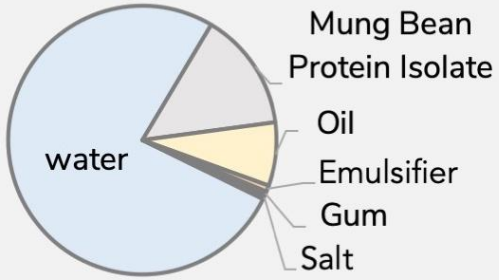
- Melt: grateable, hot viscosity, browning, stretch
- Spread: soft paste-like high viscosity
- Slice: textures/ flavors to replicate original (cheddar, camembert, feta)

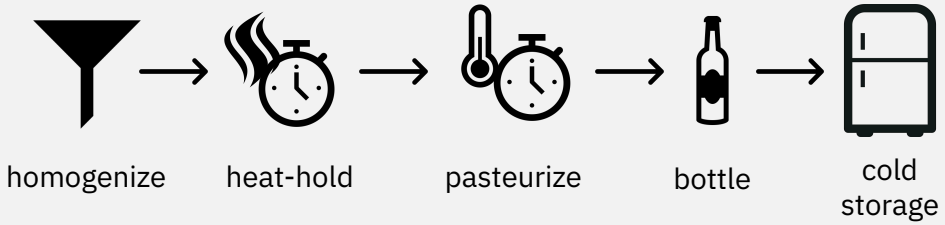
Areas of Opportunity

Flavor	Dairy flavor, reduce base off-notes
Variety	Camembert, parmesan, Roquefort, etc.
Performance	Improved melting, browning, grating
Cost	Cost parity, scale, automation
Nutrition	Dairy cheese equivalence Protein, calcium, alternative proteins Saturated fat reduction

Plant-Based Egg

Process: Mung Bean Protein Liquid Egg (for scramble)





Composition

- Varies widely depending on the egg-like functionality required and the application

Expectation

- Heat-induced gelation, foaming, emulsification, protein, mild sulfurous flavor, color

Consumption

- As a whole food (boiled, scrambled)
- For functionality (baked goods, dressing)
- Whites, yolks or whole

Areas of Opportunity

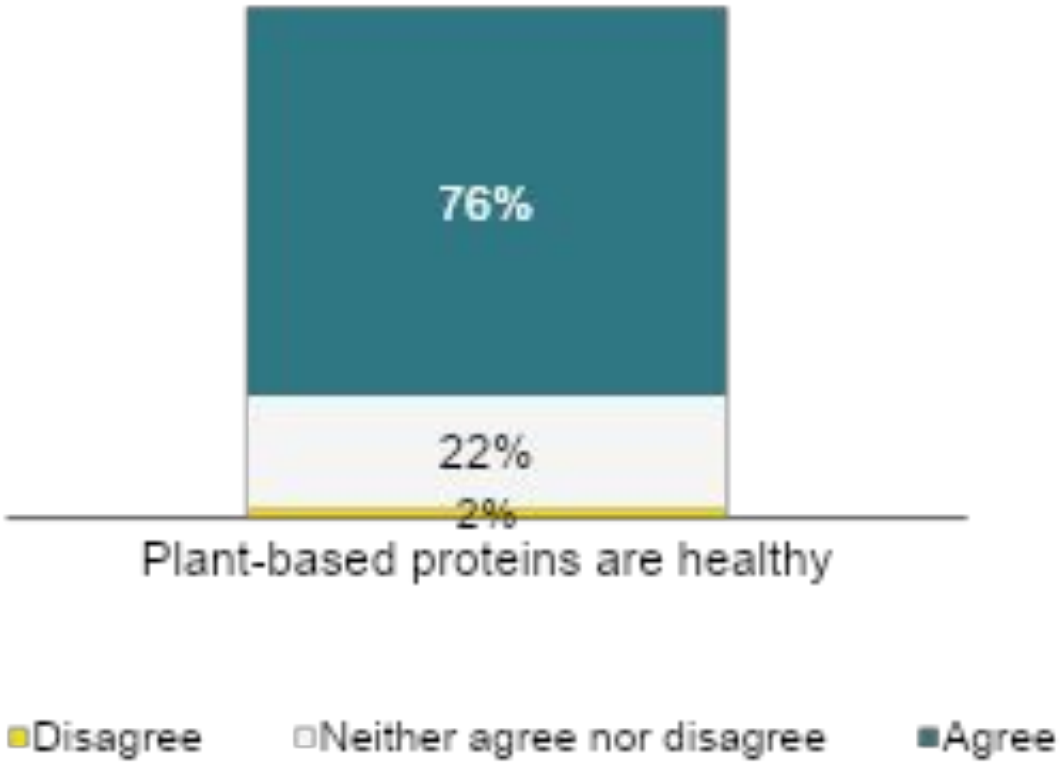
Functionality	One-size-fits-all solution
Applications	Application-specific solutions
Performance	For scrambled egg, matching cook time and texture
Clean Label	Clean label & authentic

U.S. consumer perceptions

How do plant-based protein sources compare when it comes to U.S. consumer perceptions?

Majority of consumers view plant-based proteins as healthy

Agreement with the following statements about plant-based proteins
October 2017

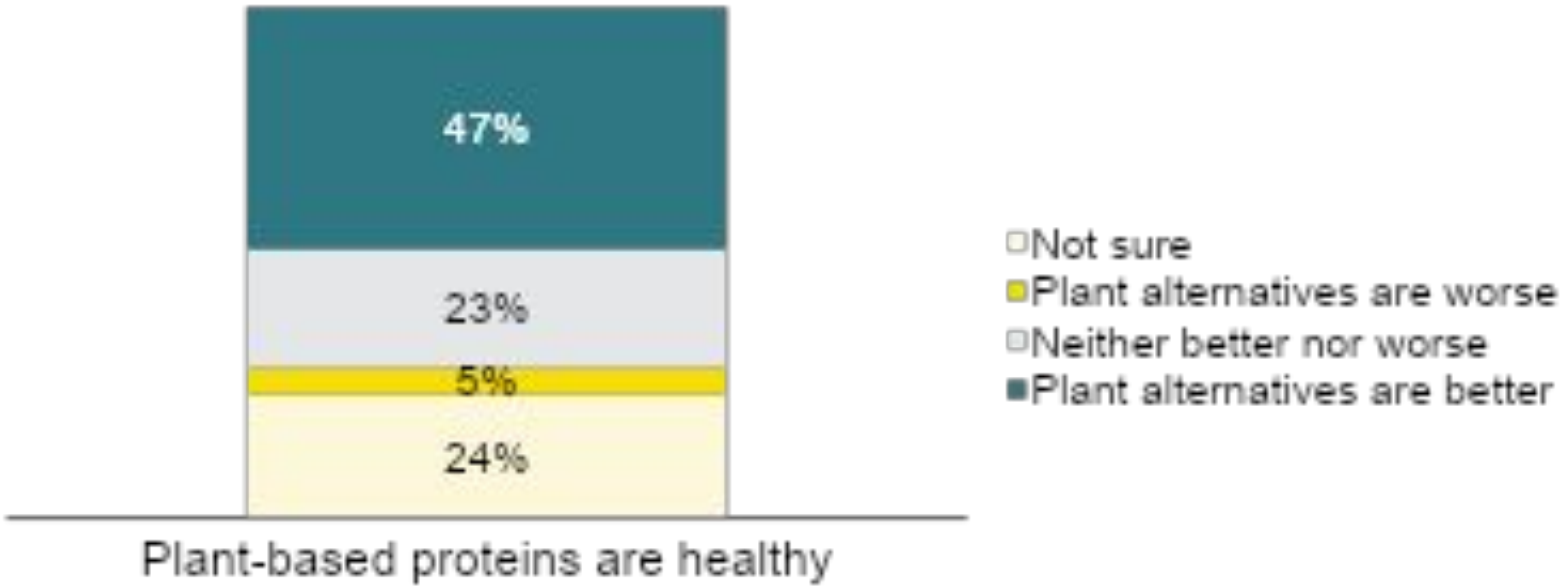


Source: Mintel “Plant-Based Proteins – US” (January 2018)

A larger percentage of consumers believe plant-based meat is better for the environment than animal-based meat

Impact of plant-based meat on the environment compared to animal-based meat

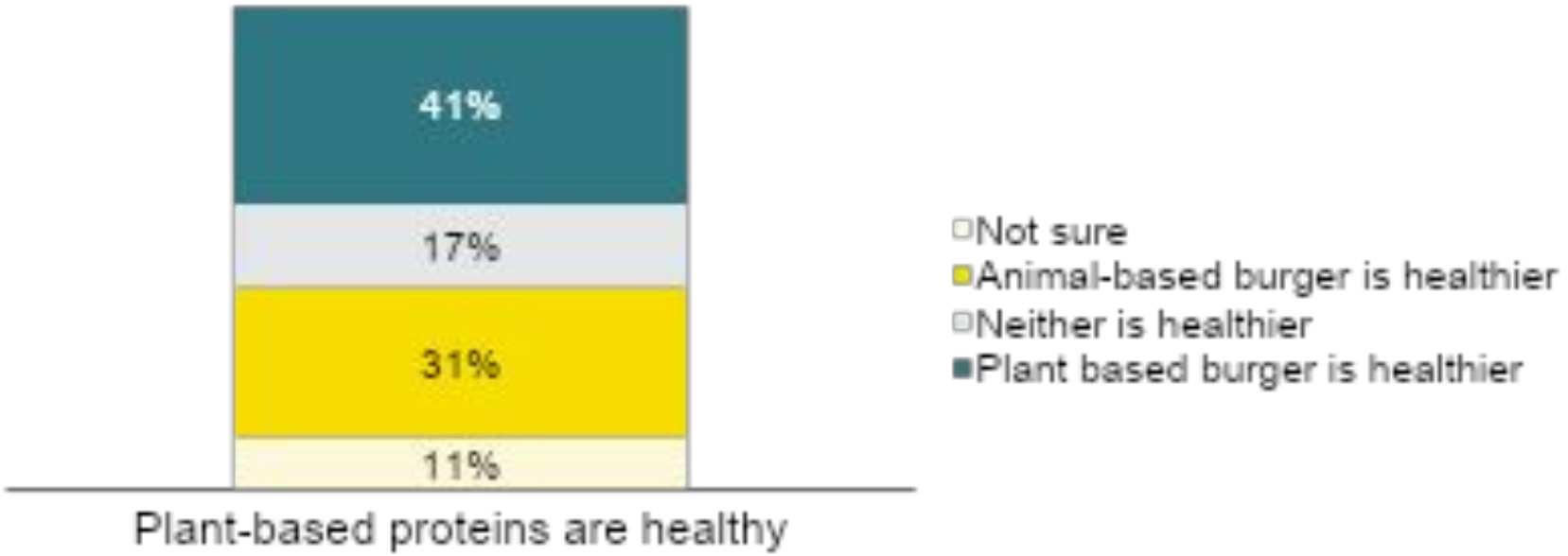
December 2019



Source: IFIC, “Plant Alternative to Animal Meat Survey” (2020)

A larger percentage of consumers believe plant-based burgers are healthier than animal-based burgers

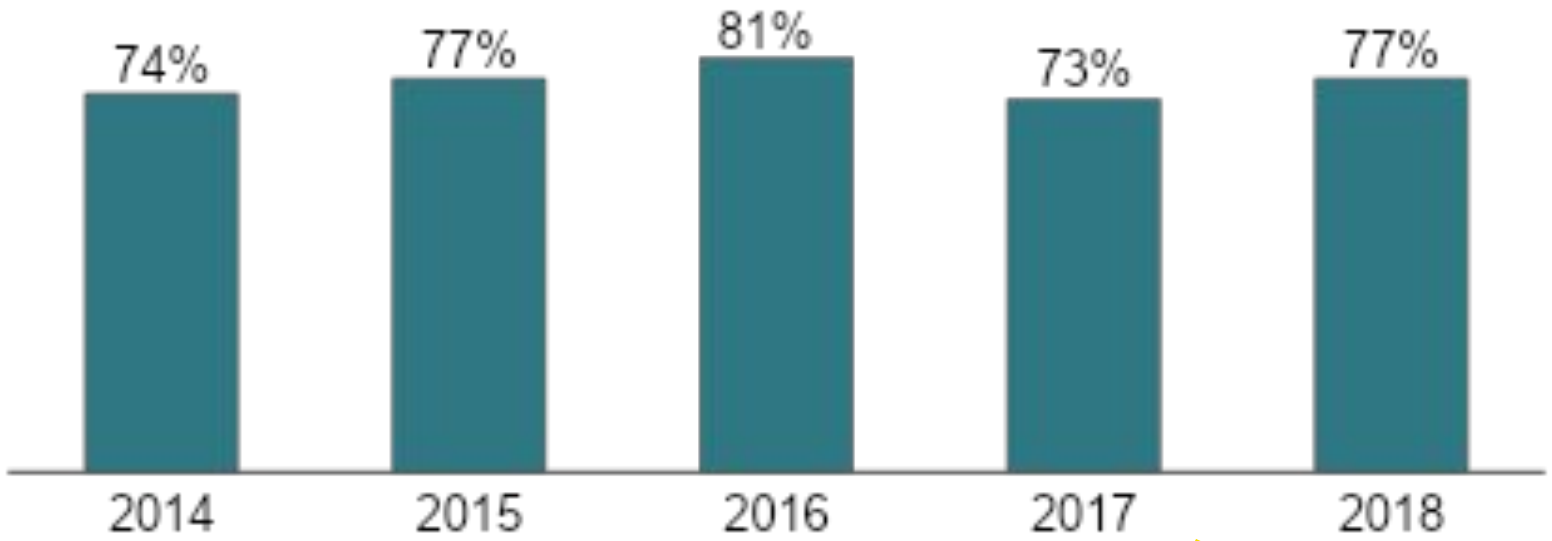
Perceived health of plant-based burgers compared to animal-based burgers
March 2020



Source: IFIC, “A Consumer Survey on Plant Alternatives to Animal Meat 2.0” (May 2020)

A consistent majority of consumers view soy as healthy

Percentage of consumers who view soy as healthy
2014-2018



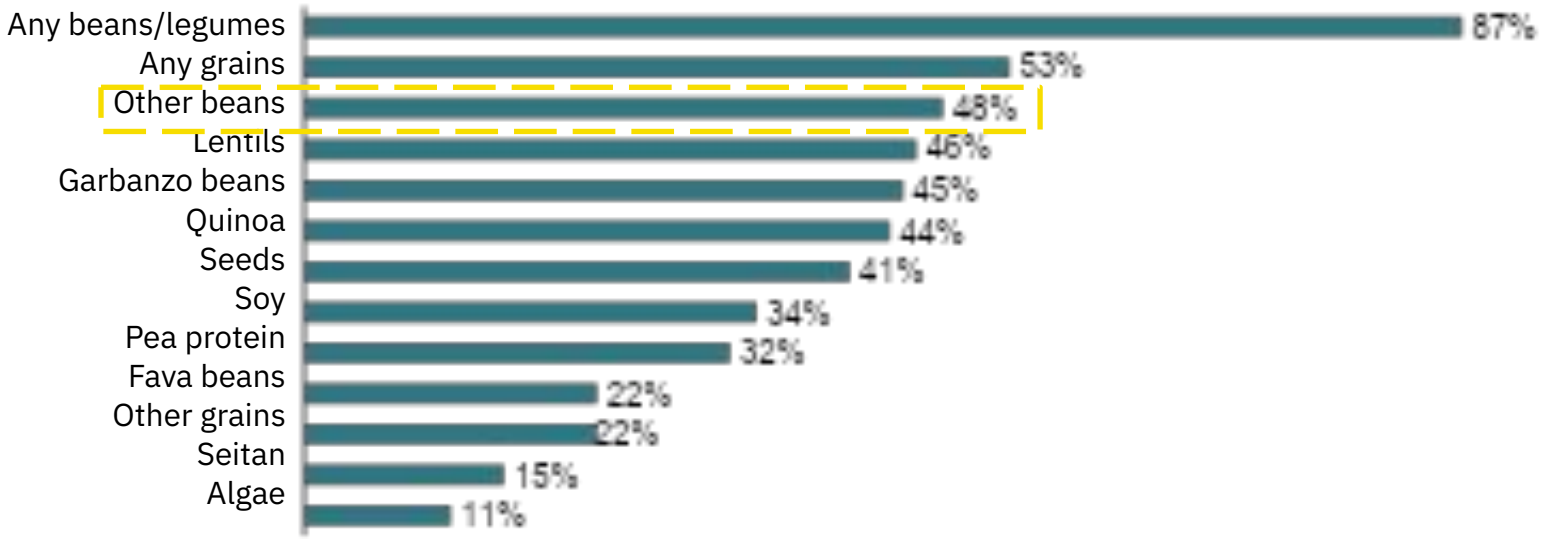
A 2019 Mintel report found that only 18% of consumers think soy is unhealthy

Source: United Soybean Board, “Consumer Attitudes about Soyfoods and Health” (2014, 2015, 2016, 2017, 2018); Mintel, “Plant-Based Proteins – US” (May 2019)

Consumer preferences may be influenced by their familiarity with protein sources

Preferences for plant-based meat protein sources

March 2020

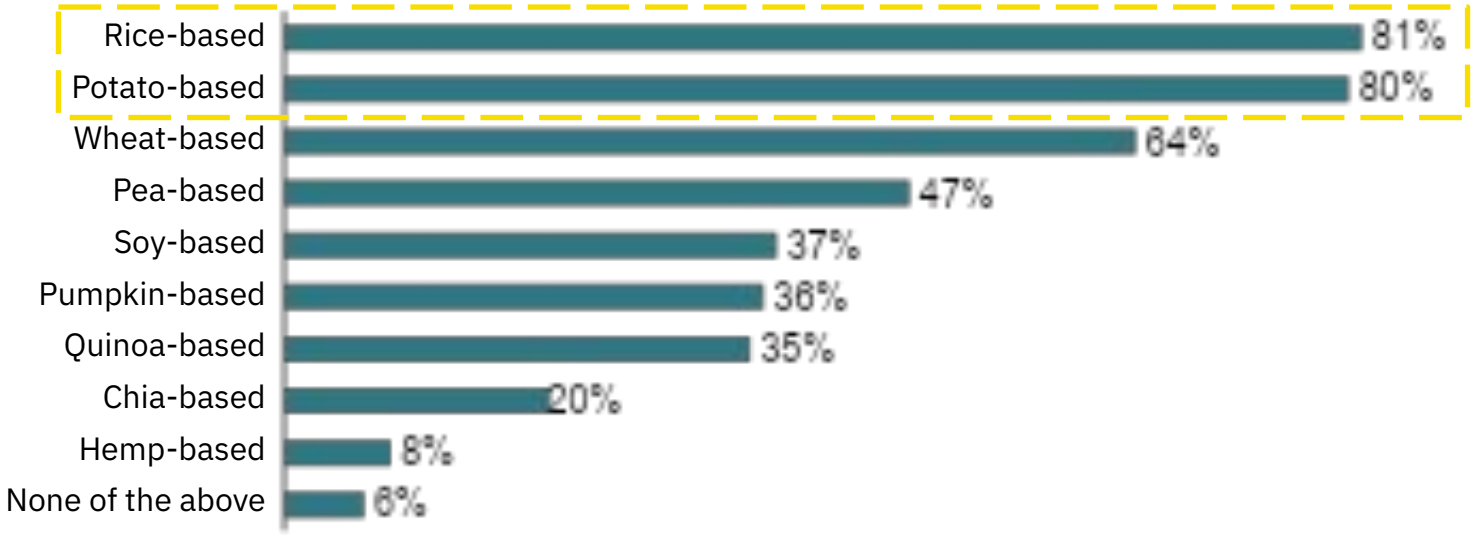


Source: Mintel, “Plant-based Proteins – US” (May 2020)

Consumer preferences may be influenced by their familiarity with protein sources

Plant-based proteins eaten by consumers

October 2017

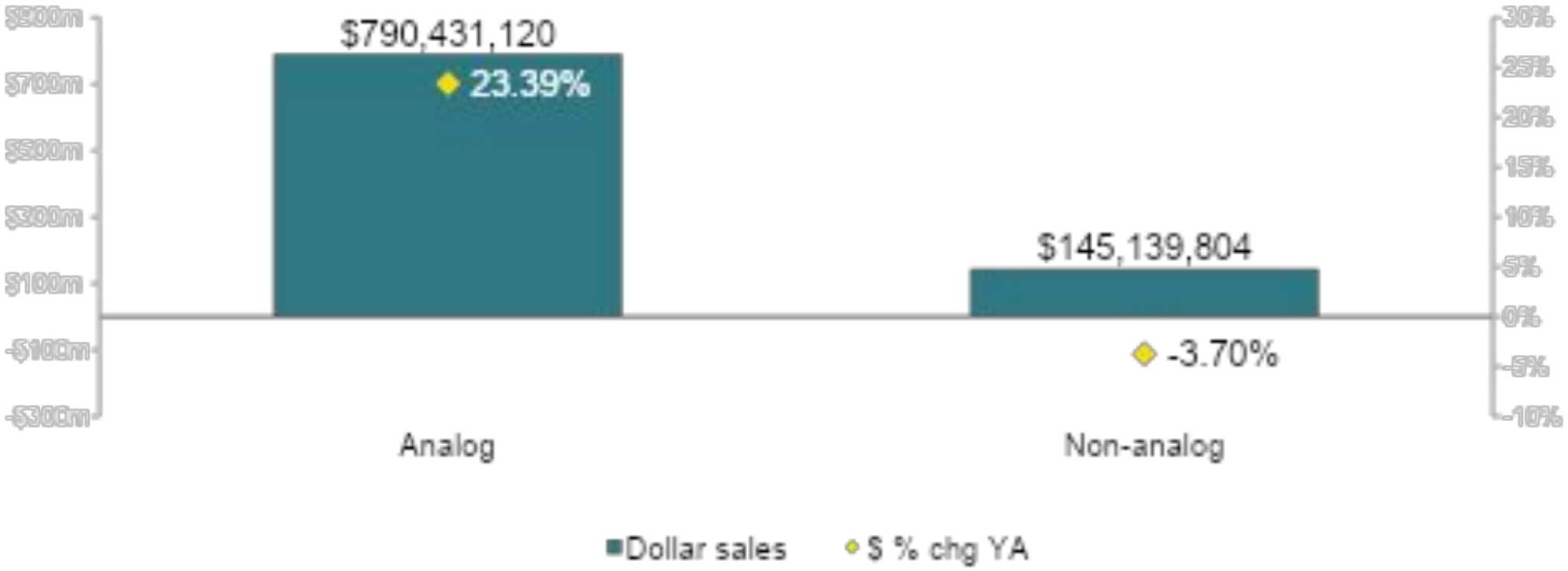


Source: Mintel “Plant-Based Proteins – US” (January 2018)

Products that are analogous to meat are growing faster than non-analog “veggie-burger” products

Analog vs non-analog plant-based meat product sales and YoY growth

2019



Note: the data presented on this slide is based on custom-GFI plant-based categories that were created by refining standard SPINS categories. Due to the custom nature of these categories, the presented data will not align with standard SPINS categories.

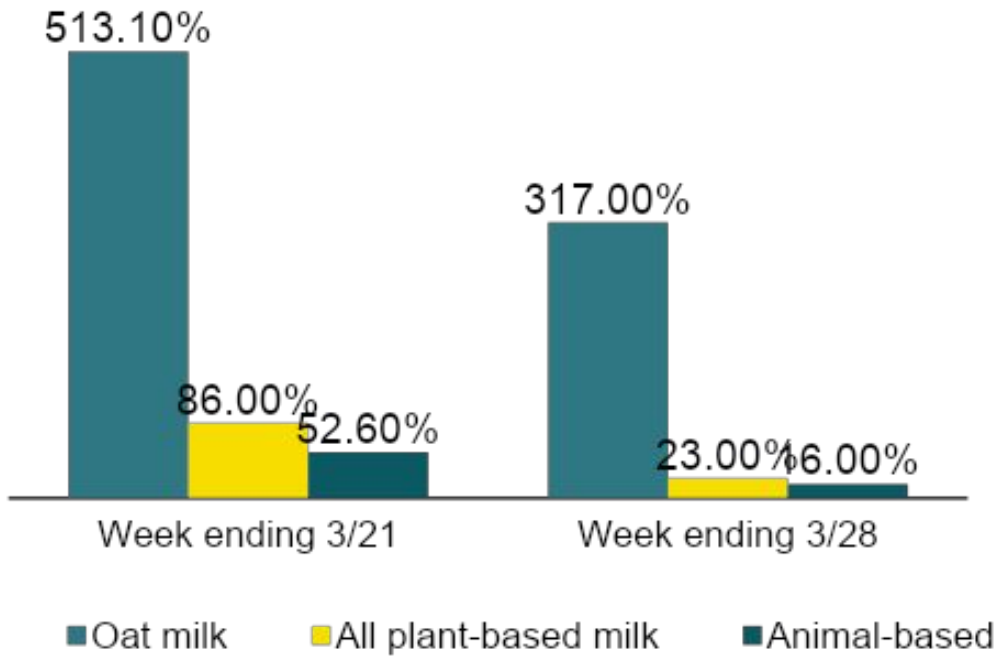
Source: SPINSscan Natural and Specialty Gourmet (proprietary), SPINSscan Conventional Multi Outlet (powered by IRI), 52 weeks ending 12-29-2019

Shifts in consumer preferences can occur rapidly after the introduction of a product

Findings from GFI/Mindlab study on implicit perceptions of plant-based foods
July 2019

"In terms of language, the dairy products which stated non-dairy/dairy clearly on pack did well [in conferring a tastiness/deliciousness], while those which used more unusual language, or emphasized ***what could be considered more unusual ingredients (oats, soy), performed poorly****"*

Oat milk and animal-based milk comparison: Increase in sales growth vs same time period in the previous year
March 21, 2020 – March 28, 2020

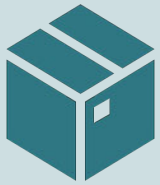


Brands should consider factors like ingredient availability and functionality alongside consumer preferences.

Source: GFI/Mindlab, "Assessing the general population's implicit perceptions of the plant-based food category" (July 2019)

Conclusion and appendix

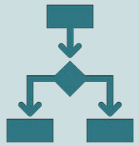
Key takeaways



There are **many potential commercial sources**—wheat and soy are leaders, with pea rapidly growing.

Commercial proteins are complex mixtures, and **viability** often requires value from **non-protein components** (e.g. oil, starch).

Properties depend on **plant source** and **process**, and formulations often benefit from **protein synergies**.



Process influences **purity**, **extracted fractions**, and **structural changes**.

There is a lack of systematic data to **objectively compare functionality**.

Optimizing protein selection is dependent on many factors, including **function**, **cost**, and **perception**.

More resources

For more resources, sign up for GFI's Plant-Based Insider newsletter:

gfi.org/insider

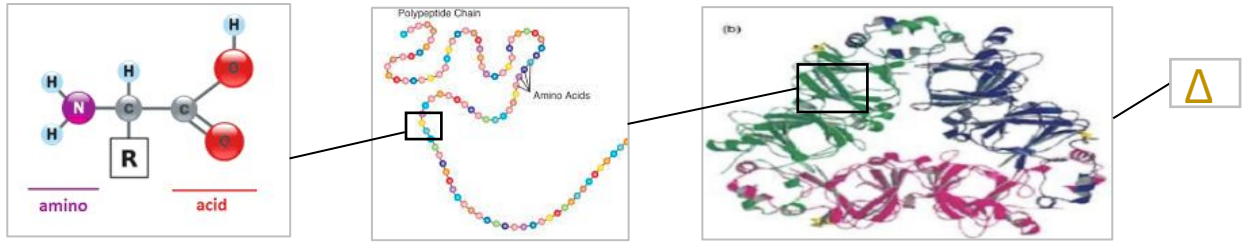
Good Food Institute

Contact us at **corporate@gfi.org** with any questions.

Glossary & FAQs

What is protein?

- Proteins are polymers of amino acids.



- The many protein types differ by size, shape, composition, biofunction, behavior in food…

albumins (water soluble)
globulins (salt soluble)
prolamins (alcohol soluble)
glutelins (acid/base soluble)

- Each plant species has a unique composition of protein types.

lentil soy corn

- Plants also contain non-protein components including:


starch


fiber


oil

What is PDCAAS?

PDCAAS is a method of evaluating the quality of a protein and was adopted by US FDA & FAO/WHO in 1993.

Protein Digestibility-Corrected **Amino Acid Score**

PDCAAS (capped at 1.0)	=	fecal true protein digestibility	X	limiting amino acid in test protein (mg/g) / same amino acid in reference protein (mg/g)
ex: Lentils: 0.51	=	0.91	X	0.56 (LAA = Tryptophan)

In the U.S., PDCAAS can be important for food labeling. When a protein claim is made, PDCAAS is used to calculate the %DV on the Nutrition Facts panel. Protein complementation can be used to enhance %DV within a product.
(%DV = percent daily value = protein grams/ daily requirement, protein grams = protein per serving * PDCAAS)

PDCAAS is often used to calculate (and optimize for) protein quality via food combination based on the debunked idea of protein complementation. Amino Acid Score is of low importance (except for severely restricted diets), as the body can store amino acids across mealtimes. Also, Protein Digestibility is typically high (>0.75).

PDCAAS doesn't consider antinutritional factors (e.g., trypsin inhibitors) and non-absorptive losses (e.g., large intestine microflora). In 2013, FAO proposed changing to DIAAS (Digestible Indispensable Amino Acid Score) which measures digestibility at the end of the small intestine.

Protein Digestibility is typically measured using rats, although an *in vitro* assay is now available from Megazymes.

How can PDCAAS be enhanced?

PDCAAS (capped at 1.0) = fecal true protein digestibility X $\frac{\text{limiting amino acid in test protein (mg/g)}}{\text{same amino acid in reference protein (mg/g)}}$

Enhancing digestibility

- **Liberating**: Proteins can be more accessible to digestive enzyme when liberated from biological structures like protein bodies.
- **Hydrolysis:** Can enhance solubility and enzyme accessibility.
- **Anti-nutritional factors:** Factors that retard digestive enzymes, e.g. trypsin inhibitors, can be removed or deactivated.

Enhancing amino acid score

- **Breeding**: Increasing the limiting amino acid concentration e.g. enhancing the lysine content of cereals.
- **Blending**: The limiting amino acid of one is complemented by its excess in another.
- **Processing**: Extract a balance of proteins types with an overall better balance of amino acids.

What is a Branched Chain Amino Acid (BCAA)?

- Amino acids with a branched aliphatic side chain, i.e. a carbon attached to 3+ other carbons.
- Includes leucine, isoleucine, valine and 2-aminoisobutyric acid.
- Synthesized in plants.
- Helps build muscle, decrease muscle fatigue and alleviate muscle soreness.
- Can have a negative impact on mood by interfering with tryptophan, the precursor to serotonin (the happiness hormone). Excessive intake may reduce lifespan, increase appetite, induce weight gain.

What are methods for lowering the cost of plant proteins?

- **Agronomic yield improvement** (crop and protein)
- **Scaling** (agricultural production, extraction & use)
- **By-product valorization** (oil, starch, fiber, extracts)
- **Shared supply chain** (multiscale co-manufacturing, transport, etc.)
- **Low-cost extraction** (lower inputs, higher thruput & yield)
- **Localized production** (farm, processing, food manufacturing)

What are methods of texturizing proteins?

Method	Example
Coarse aggregate gelation	Tofu
Fine network gelation	JUST Egg
Hydrocolloid gelation	Plant based yogurts
Low moisture extrusion	TVP
High moisture extrusion	Gardein
Shear cell	Wageningen
Fiber spinning	Ford, General Foods, Bac'O's
Electrospinning	Cultured meat scaffolds, Unilever WO2012084427A1
Freeze texturization of a gel	Freeze-thaw tofu
Deep-fry texturization	Tofu puffs
Dry heat	Tofu crumbles, baked tofu
Skin formation on boiling	Tofupi –> vegetarian duck
Fibers in a protein gel	Guelph
Dough formation	Seitan
Mycelia	Quorn, tempeh
3D printing	Redefine Meat

What are antinutritional factors?

Antinutritional factors are compounds that interfere with the absorption of nutrients. Examples include:

Phytic acid	Binds minerals (e.g. calcium, magnesium, iron, copper, zinc) thereby preventing absorption Common in the hulls of nuts, seeds and grains
Protease inhibitors	Inhibits digestive proteases (trypsin, pepsin etc) preventing protein digestion & absorption Example: Bowman–Birk trypsin inhibitor is found in soybeans
Lipase inhibitors	Interfere with enzymes, such as human pancreatic lipase, that catalyze lipid hydrolysis Found in some plants
Amylase inhibitors	Inhibits enzymes that break starches into simple sugars, thereby preventing absorption. Present in many types of beans including white kidney beans
Oxalic acid, oxalates	Binds to calcium and prevents its absorption Present in many plants, particularly in rhubarb, tea, spinach, parsley and purslane.
Glucosinolates	Prevents the uptake of iodine, affecting the function of the thyroid Found in broccoli, brussels sprouts, cabbage, mustard greens, radishes, cauliflower
Avidin	Binds to biotin (vitamin B7) prevent absorption Found in raw egg whites
Flavonoids	Group of polyphenols (inc. tannins), some bind metals (iron, zinc) or inhibit digestive enzymes Found in many plants
Saponins	Compounds with soap-like properties, often bitter or astringent and act like antifeedants Found in many plants including oat, spinach, and quillaja

What is a lectin?

- Carbohydrate binding proteins ubiquitous in nature & found in many foods.
- Major class of antinutrients.
- Some are beneficial, while others are powerful toxins (e.g. ricin from castor plant).
- Some foods, such as beans and grains, need to be cooked or fermented to reduce lectin content.

- Haemagglutenins are lectins that can agglutinate (clump) red blood cells & found in many legumes e.g. raw kidney beans, soybeans and fava bean.

Leucoagglutinin is a toxic phytohemagglutinin found in raw Vicia faba (fava bean).

Image Source: https://en.wikipedia.org/wiki/Lectin#/media/File:Phytohemagglutinin_L.png

What is a trypsin inhibitor?

- Trypsin & chymotrypsin are enzymes that break down proteins during digestion.
- A trypsin inhibitor is a protein that reduces trypsin and (to a lessor extent) chymotrypsin activity by acting as a competitive and irreversible substrate.
- It prevents full and efficient utilization of dietary protein and is therefore considered an anti-nutritional factor (ANF).
- It is produced by many plants (including common food crops) as a defense mechanism against being eaten by animals.
- Trypsin inhibitor is inactivated by heat e.g. boiling soybeans for 14 minutes inactivates about 80% of the inhibitor.

What is an alkaloid?

- Alkaloid is a broad term for organic compounds that contain nitrogen.
- “True alkaloids” contain nitrogen in the heterocycle and originate from amino acids.
- Many have biological activity e.g. quinine (antimalarial) caffeine (stimulant), atropine (toxic, ephedrine (antiasthma).
- In plants, their role is often to dissuade animals from eating them.
- Almost all taste bitter.

What is an aflatoxin?

- A class of carcinogenic & mutagenic mycotoxins.
- Produced by the molds Aspergillus flavus (hence the name) & Aspergillus parasiticus.
- Found in improperly stored food commodities.
- Can affect several plant protein sources: millet, peanuts, rice, sesame, sorghum, sunflower seeds, corn, tree nuts & wheat.
- Children are particularly affected by exposure.
- Associated with stunted growth, delayed development, liver damage, and liver cancer.
- Metabolized by the liver to a reactive epoxide intermediate or hydroxylated to become the less harmful aflatoxin M1.

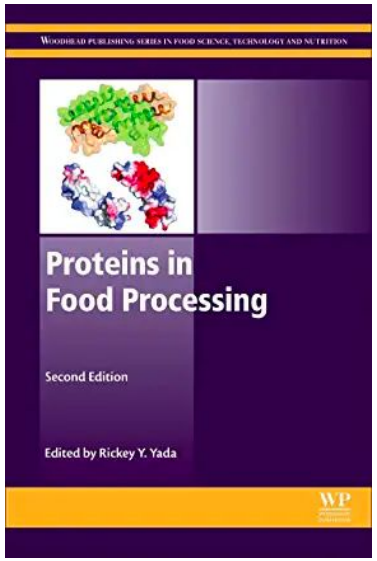
Is it possible to predict allergenicity potential of novel proteins?

- Allergenicity is related to IgE-sensitization towards proteins. An allergic response is triggered by recognition of the protein's 3D structure and its amino acid sequence.

- To predict allergic potential, the current approach is based on comparison to known allergens - single hexamer peptide hits and sequence identity thresholds – as per FAO/WHO guidance for GM plant foods. This leads to many false positives including up to 90% of all human proteins.

- More reliable methods may help provide more useful prediction tools, such as AllerCatPro.

Information sources



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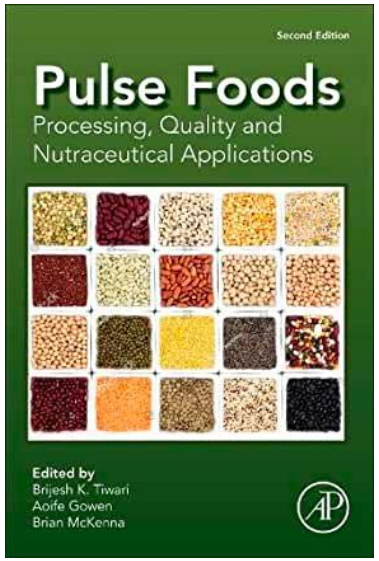

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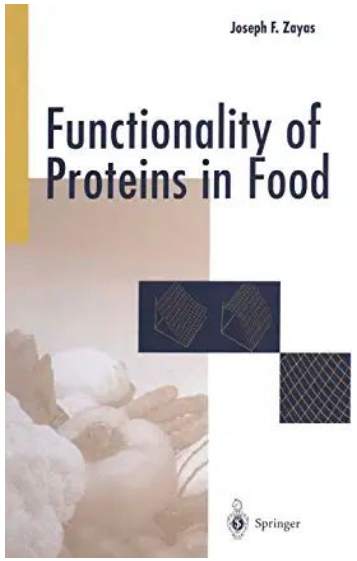

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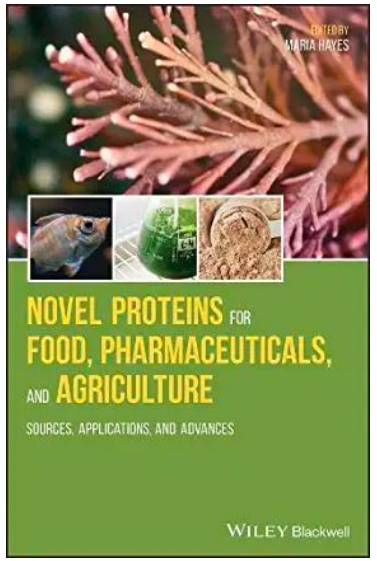

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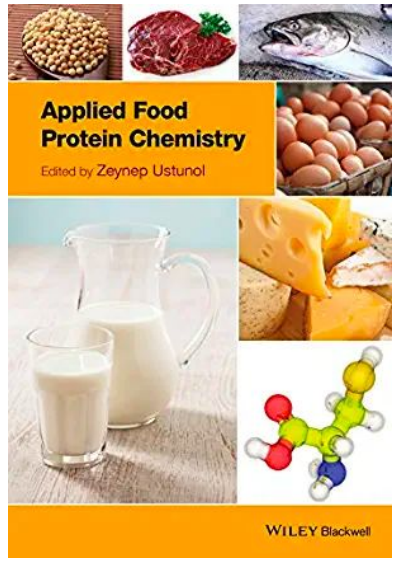

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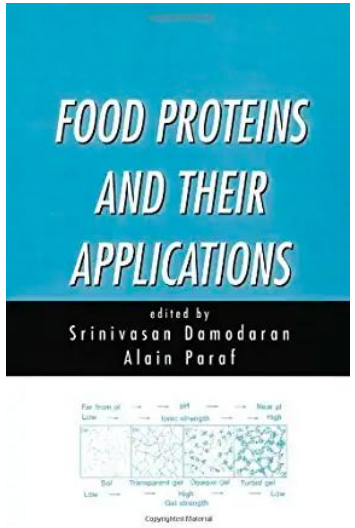

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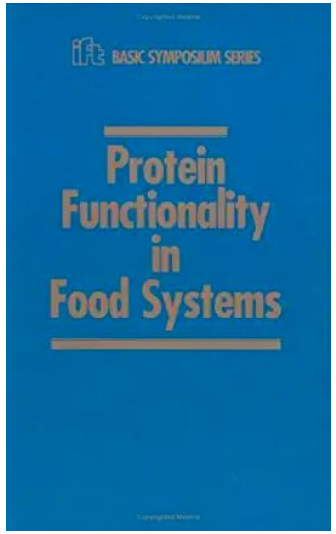

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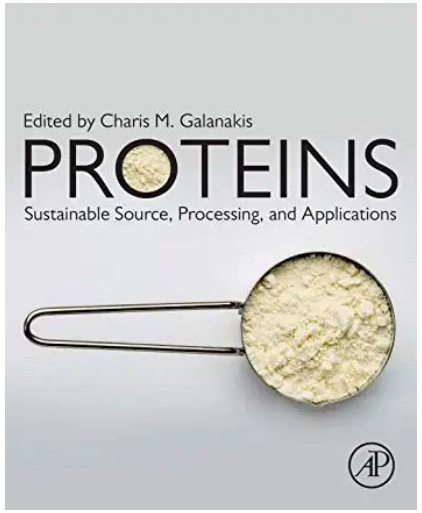

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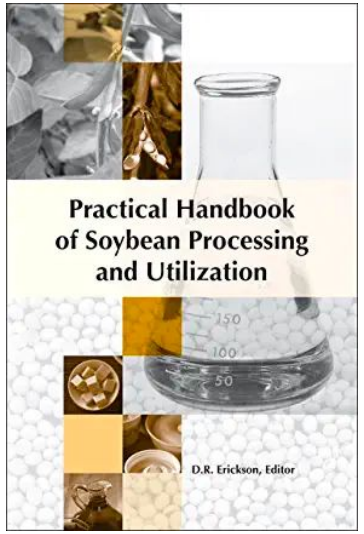

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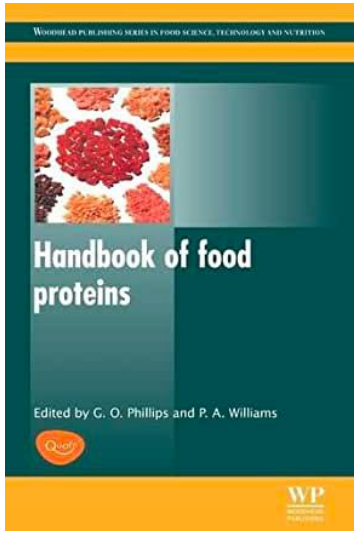

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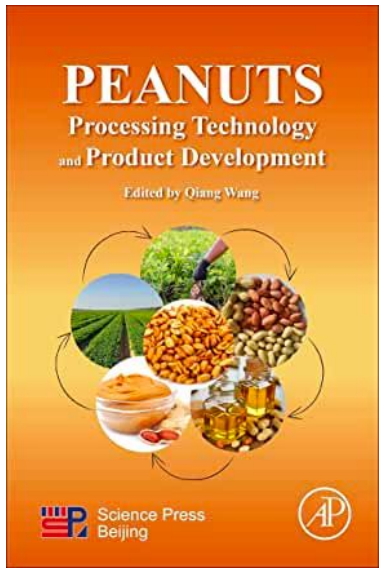

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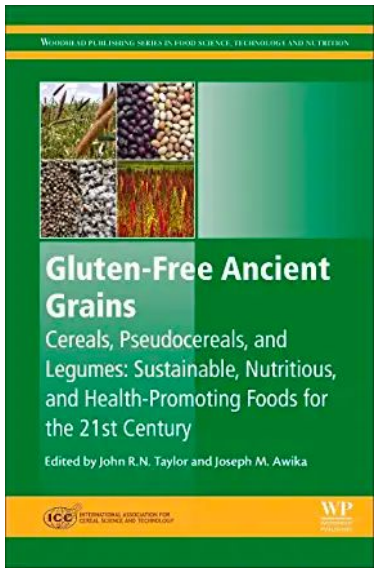

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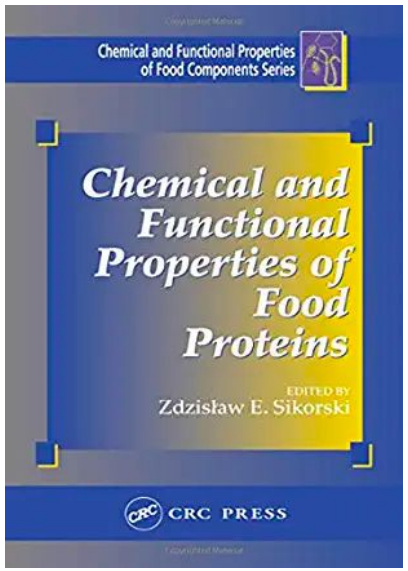

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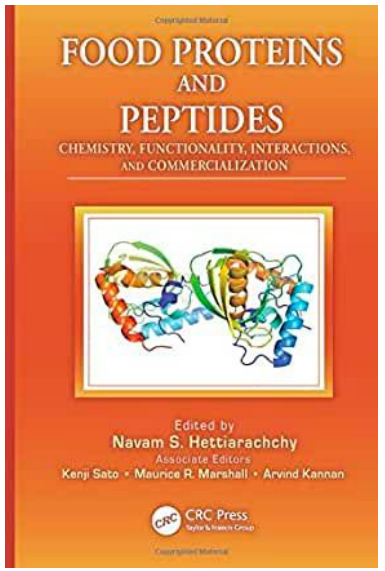

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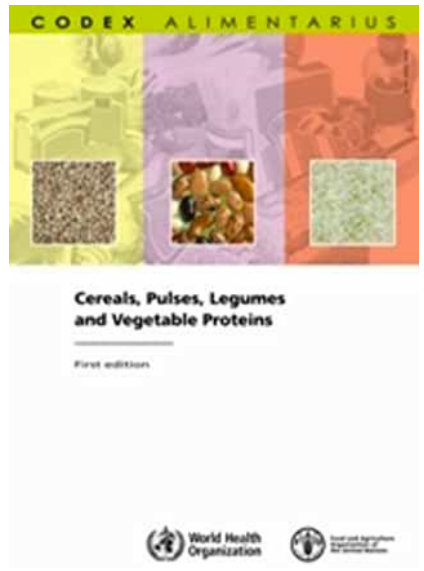

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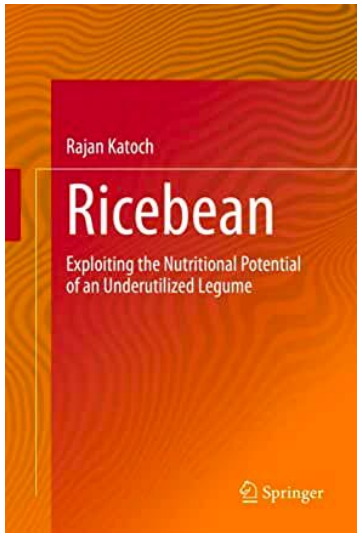

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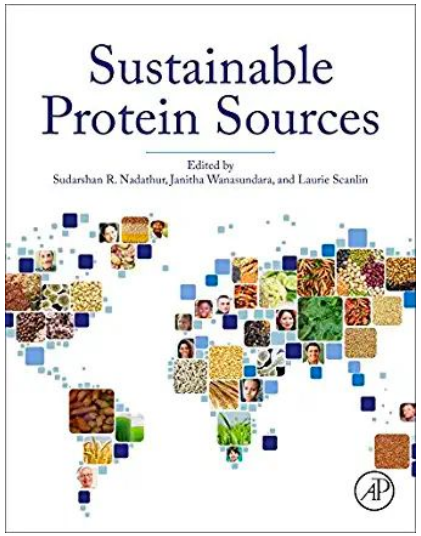

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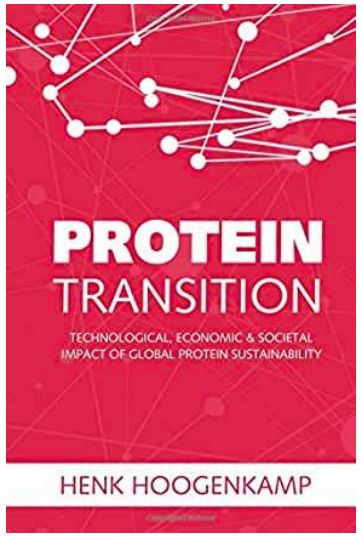

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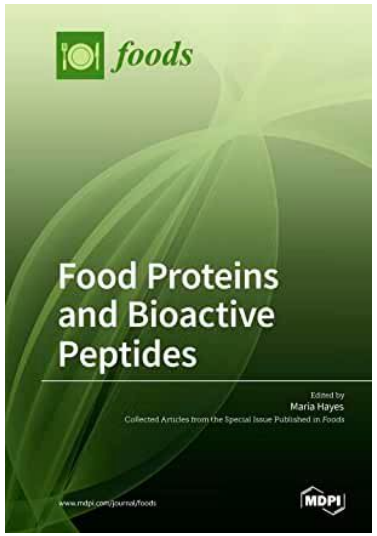

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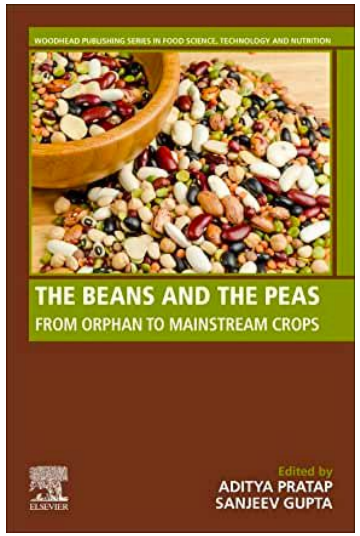

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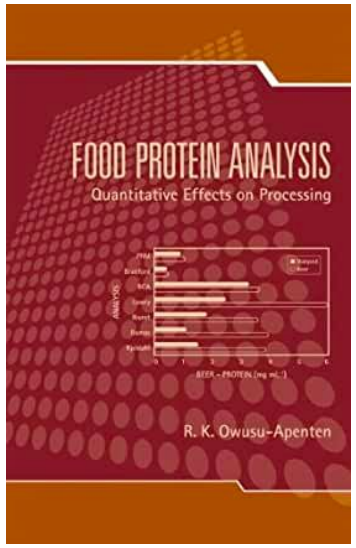

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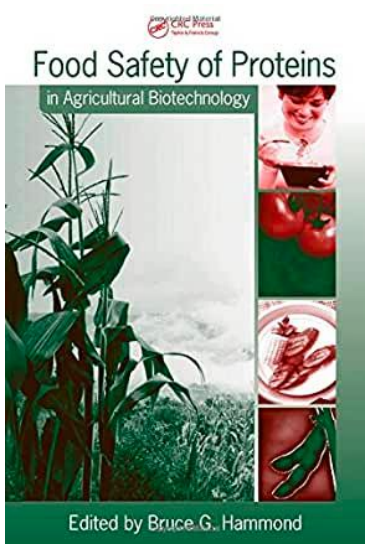

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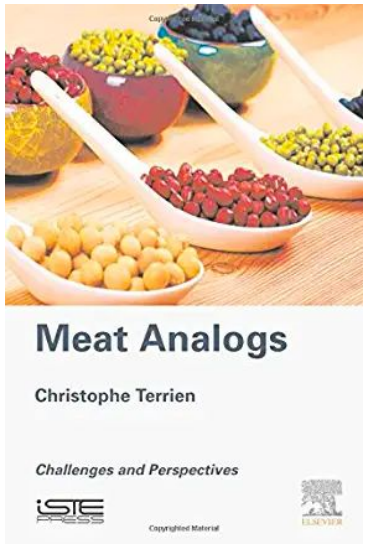

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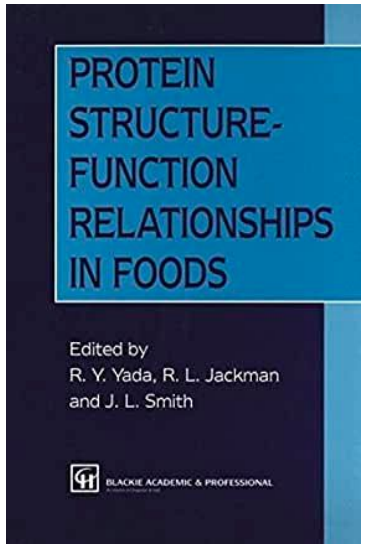

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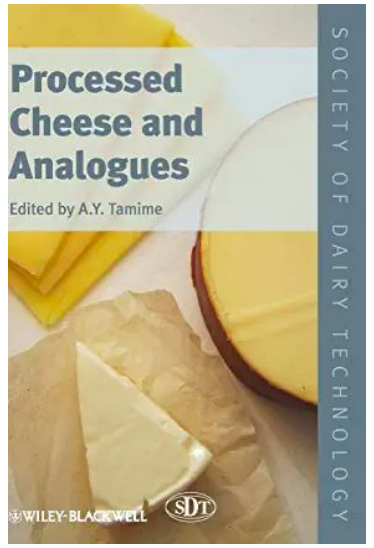

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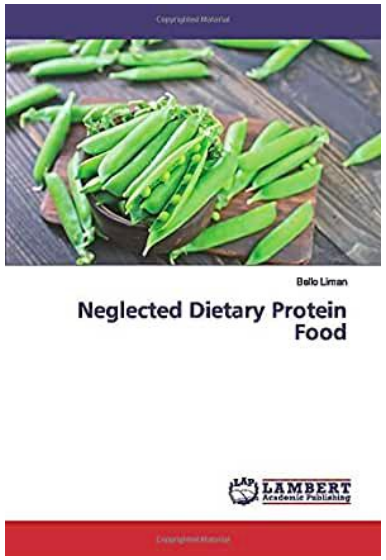

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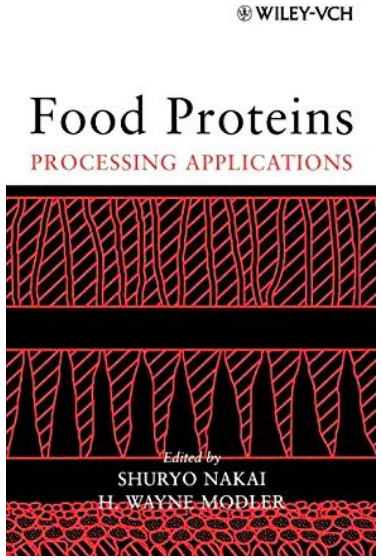

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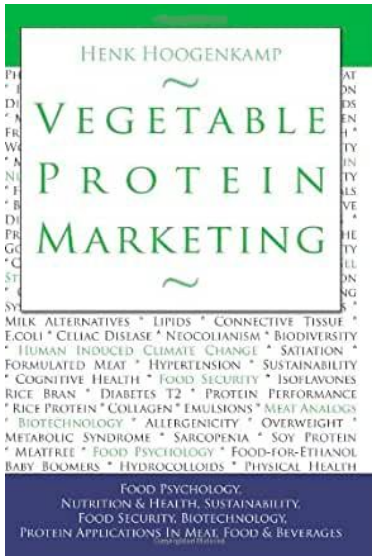

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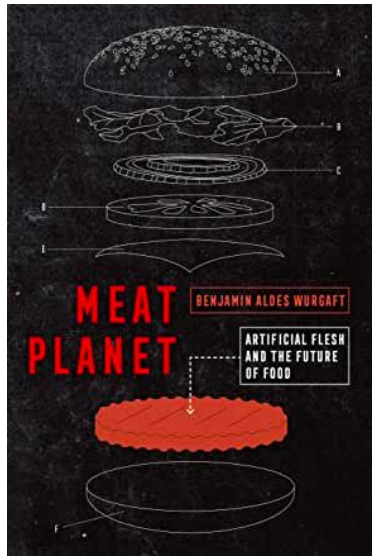

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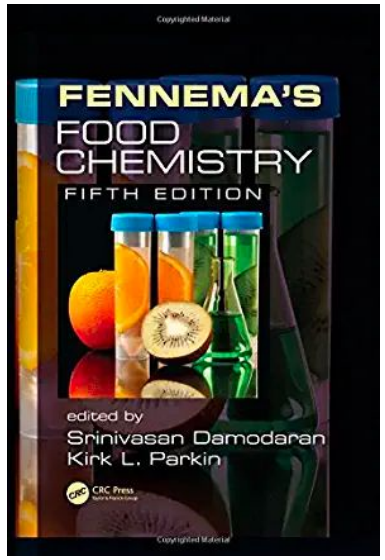

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