

## 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.



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)



=%



**Availability** 

Regulatory

Safety









Familiarity with use







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.

Oil

Defatted flour

Whole flour

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.

Carbs

Concentrate

Isolate

Carbs

## **Protein extraction**



## (1) 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 colorcoded 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
ок	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								

## **Protein source type**

### Legume / Pulse / Oilseed

### Vegetable / Fruit / Nut / Cereal

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

- 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

<b>Protein Nutrition</b>			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			



## 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

## **Properties**

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



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

### **Applications**

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

### **Dry Composition**

- Protein
- Lipid
- Fiber
- Digestible carbohydrate
- Other

#### **PRODUCT EXAMPLES**







Soy Creamy



1 Drand	
Protein Nutr	ition

**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)



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



- 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

### Applications

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

## Dry Composition



ORIGINAL

ripple





## Wheat

Type: Cereal

### Unique functionality and widespread availability contribute to popularity

<b>Protein Nutrition</b>			
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



- **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**







## Canola

Туре: **Oilseed** 

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

<b>Protein Nutrition</b>			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			

- 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

## Properties

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



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

## Dry Composition



## Applications

- Sausages
- Mayonnaise (hydrolyzed meal)



# Chickpea

Type: Legume / Pulse

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

<b>Protein Nutrition</b>			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			

## Sourcing

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



- 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







## Fava Bean

*Type: Legume / Pulse* 

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

<b>Protein Nutrition</b>			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			



## Sourcing

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



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

## Dry Composition





- Savory flavor
- Gelling
- Water retention
- Emulsifier



### Applications

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



## **Lentil** Type: Legume / Pulse

## Abundant crop with highly soluble protein

<b>Protein Nutrition</b>			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			



## Sourcing

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



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



- 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



### Applications

- Pasta
- Burgers
- Crackers

### **Dry Composition**

- Protein
- Lipid
- Fiber
- Digestible carbohydrate
- Other







Lupin Type: Legume / Pulse

A high-concentration protein source with emulsification properties

<b>Protein Nutrition</b>			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			



## Sourcing

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



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

## Dry Composition

- Protein
- Lipid
- Fiber
- Digestible carbohydrate
- other





- High solubility
- Emulsification
- Beany & bitter



- Dairy-free milk
- Bakery



# Mung Bean

Type: Legume / Pulse

Abundant Asian bean with high protein and gelling functionality

Protein Nutrition			
Allergenicity			
lavor			
unctionality			
Cost			
Crop Supply			

## Sourcing

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



- **PDCAAS 0.55** ٠
- Limiting AA: Met & Cys
- Rich in fiber, potassium, magnesium
- Antinutritional factors

## **Dry Composition**





- High solubility
- Gelling
- Savory flavor



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



## Navy Bean

Type: Legume / Pulse

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

<b>Protein Nutrition</b>			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			

### Sourcing Native to Sou

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



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

## Dry Composition

- Protein
- Lipid
- Fiber
- Digestible carbohydrate
- other



#### PRODUCT EXAMPLES





Properties

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



## Applications

- Baked beans
- Protein: largely unexplored



## Peanut

Type: Legume / Oilseed

### Abundant protein source providing minimally processed high protein flour

Protein Nutrition			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			

## .

- 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

## Properties

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



- 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.)

## Applications

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

## Dry Composition

Protein
Protein, 28%
Lipid
Fiber
Digestible carbohydrate
Other





## Sunflower

*Type: Oilseed* 

#### An underutilized oilseed byproduct with emulsification functionality

Protein Nutrition			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			



## Sourcing

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



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



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

**Applications** 

Meat analogs

PB ice cream

**Supplements** 

Bakery

Dressings

### **Dry Composition**





# Almond

Type: **Nut** 

#### **Consumer-friendly with** smooth texture and mild taste

<b>Protein Nutrition</b>			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			

## Sourcing

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



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



## **Nutrition**

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



## **Applications**

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

## **Dry Composition**

Protein, 22% Protein

Lipid

Fiber

Digestible carbohydrate

Other









## **Corn** Type: **Cereal**

A major under-utilized low allergenicity protein

<b>Protein Nutrition</b>			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			



## 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

## Properties

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



- PDCAAS 0.37
- Limiting AA: lysine & tryptophan

Zein: encapsulation, edible

coatings (nuts, candy), bakery

- Digestibility enhanced by enzyme hydrolysis
- Antinutritive tannins

**Applications** 

glaze

## Dry Composition

Protein

11%

- Protein
- Lipid
- Fiber
- Digestible carbohydrate
- Other





**Oat** Type: **Cereal**  Abundant protein source providing minimally processed high protein flour

Protein Nutrition			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			

## Sourcing

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

Properties

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



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



## Applications

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

## **Dry Composition**

Protein Protein, 15%

Lipid

Fiber

Digestible carbohydrate

Other







## Potato

*Type:* **Vegetable** 

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

<b>Protein Nutrition</b>			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			

### Sourcing Mainly produ

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



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

## **Dry Composition**

- Protein 7.4% protein
- Lipid
- Fiber
- Digestible carbohydrate
- other



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



## Applications

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





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



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



• PDCAAS 0.79

**Applications** 

Consumed as a grain

- Limiting AA: Phe & Tyr, high in Lys
- High in manganese, magnesium, phosphorus & vitamins B1, B2, B6, B9

Incorporated into products as a flour

• Allergenicity: Low, possible saponin sensitivity

## Dry Composition

16%

protein

nrbuue

QUINOA

- Protein
- Lipid
- Fiber
- Digestible carbohydrate
- other





## **Rice** Type: **Cereal**

A byproduct of hydrolyzed starch produced from a globally produced grain

Protein Nutrition			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			



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



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

## Dry Composition



BEYOND

BEYOND

166 MEL



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



## Applications

- Meat analogs
- Dairy alternatives
- Bakery







# Sorghum

An under-developed byproduct of starch & ethanol production

Protein Nutrition			
Allergenicity			
Flavor			
Functionality			
Cost			
Crop Supply			

## Sourcing

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



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



- PDCAAS 0.29
- Limiting AA: Lysine
- Dominant protein: kafirin (insoluble)

Grain: GF bakery, beer, sweeteners,

- Poor digestibility
- Allergenicity: Rare

**Applications** 

tortillas

No known protein uses

## Dry Composition

- Protein
- Lipid
- Fiber
  - Digestible carbohydrate
  - other







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

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

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%)

	•	
•		•
٠		•

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)



## **Combining plant proteins**

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



Protein content & quality







Allergenicity & intolerance



perception

**Availability** 

**Functionality** 



Aroma, flavor, texture, mouthfeel, color

Cost

## **Examples of synergistic combinations**

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



### Bricks and mortar

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



### Complementary companions

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



### 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



## **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.



## Bambara Bean



## **Beach Pea**

# Camelina



## **Cashew Nut**



## Chia

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



## **Duck Weed**







## Hemp



## Jackfruit

- 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
- 35% protein including phycobiliproteins, not commercially extracted
- Very rich in iodine
- Culinary uses, also dried and eaten uncooked
- 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, eggsubstitute, gluten-free flour mixes, shakes/smoothies
- 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
- Easy to grow, resistant to pests, high temperatures & drought
- 18-32% protein, high calcium, manganese, magnesium, potassium
- Seed flour used in baking, good for thickening and binding



## Lima Bean

Mesquite Bean

- Capable of fixing nitrogen to restore soils
- 19-29 % protein
- Mainly culinary use, Japanese confections
- Presence of anti-nutritional factors (Cyanogenic glucosides)
- 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
- 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
- Successful cover crop with beans containing 20-29% protein.
- Produces L-DOPA which has various medicinal properties
- Contains various antinutrients.

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## Penny Cress

Mucuna Bean

- 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



## Millet



## **Pigeon Pea**



## Pongamia



## Potato Bean

**Pumpkin Seed** 

Sesame

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



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

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## Wheat Grass

Watermelon Seed

- Kemza® Is a perennial crop that retains topsoil & sequesters carbon
- Grain contains 10-21% protein
- Compared to regular wheat: higher vitamins, minerals,  $\omega 3.$  less gluten, antinutrients



## Yam Bean

**least** 

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



**Texturized Proteins** 

## 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** 





#### 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



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

## **y** Combining individual products with positive attributes into a single product

FlavorDairy flavor, no off-notesExperienceCreamy textureApplicationsAcid & heat tolerance (barista style)CostParityClean LabelClean label stabilizationAllergenicityAllergen-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)



,	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		





#### Composition

 Varies widely depending on the egglike 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



Plant-based proteins are healthy

Disagree Neither agree nor disagree Agree

# 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



Plant-based proteins are healthy

## 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*



Plant-based proteins are healthy

## A consistent majority of consumers view soy as healthy

Percentage of consumers who view soy as healthy 2014-2018



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# Consumer preferences may be influenced by their familiarity with protein sources

**Preferences for plant-based meat protein sources** *March 2020* 



# Consumer preferences may be influenced by their familiarity with protein sources

Plant-based proteins eaten by consumers October 2017



# Products that are analogous to meat are growing faster than non-analog "veggie-burger" products



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.

# **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:







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



## What is 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:





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



## 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	Х	limiting amino acid in test protein (mg/g) same amino acid in reference protein (mg/g)
<i>ex:</i> Lentils: 0.51 =	=	0.91	Х	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

Х

<u>limiting amino acid in test protein (mg/g)</u> 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.

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- **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

Tofu **Coarse aggregate gelation** JUST Egg Fine network gelation Plant based yogurts Hydrocolloid gelation Low moisture extrusion TVP High moisture extrusion Gardein Wageningen Shear cell **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 Tofu crumbles, baked tofu **Dry heat** Skin formation on boiling Tofupi –> vegetarian duck Fibers in a protein gel Guelph **Dough formation** Seitan Mycelia Quorn, tempeh **Redefine Meat 3D** printing

#### 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).

## 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 <u>A</u>spergillus <u>fla</u>vus (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 <u>AllerCatPro</u>.

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