Overview of Plant-Based Meat Manufacturing

PLANT-BASED MEAT MANUFACTURING BY EXTRUSION

November 27, 2019

MJ Kinney
Food Scientist

Zak Weston
Food Service Analyst

JD Bauman
Corporate Engagement Intern

THE GOOD FOOD INSTITUTE

Executive Summary

An increase in the demand and development of new and better plant-based meat products provides huge opportunities for food product developers and manufacturing companies. This document is an introduction to, and overview of, the technologies required to capitalize on these opportunities. Fortunately, a variety of well-understood and closely related food processes already exist to use as a starting point, allowing a template-like approach for raw materials and overall processing systems. Extrusion is an example of such a template; it is widely used in producing cereals, puffed snacks, bars, and pastas, and serves as a key platform in the production of plant-based meat.

This report offers a general overview of how to create plant-based meat using extrusion. It provides a practical model via process flow charts of two major categories: (1) restructured and (2) whole muscle plant-based meat products. Although the technological scope of this resource is limited to the use of extrusion, extrusion is not the only means of producing high-quality plant-based meat products.

In formulation, there is no one way to create a product. As a developing category, plant-based meat production processes will simultaneously create, borrow, and repurpose novel knowledge, ingredients, equipment, and distribution from well-established food value chains—including those from animal-based food. We hope this resource serves as a roadmap to systemize a standard set of processes, offer insights to scale production and, with the help of our directories (see Appendix), readily locate a means to a technical solution at various stages of the product development process. Further, we hope this overview helps prospective manufacturers assess the feasibility of plant-based meat production in their own facilities.

Table of Contents

Background

What is plant-based meat?

Plant-based meat closely resembles an animal-based meat product in its organoleptic properties, using one or a combination of alternative protein ingredients. The scope of this report is limited to addressing the creation and potential process systems for plant-based meat involving extrusion technology.

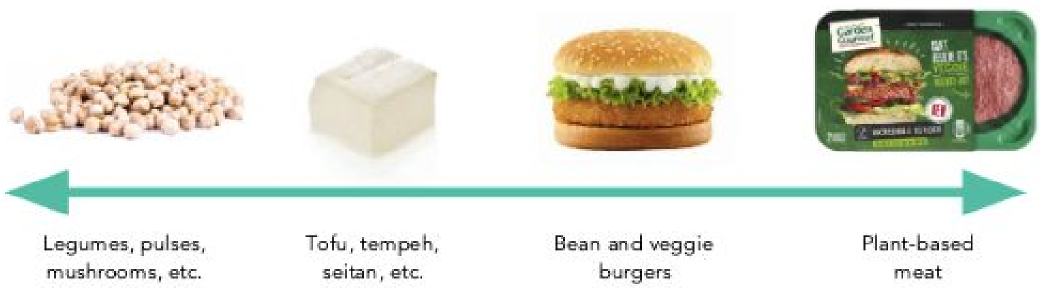

Figure 1. Alternative Protein Product Spectrum | Products formed from alternative protein sources compose a spectrum of finished product options ranging from (1) whole sources of plants (as well as microbial sources, such as fungi), (2) homogenized, pressed, and fermented products (e.g., tofu, tempeh, seitan), (3) ground vegetable-based burgers, and (4) plant-based meat.

What is alternative protein?

Alternative protein is a catch-all phrase that can be interpreted as ingredients derived from non-animal sources. However, not all non-animal sources are technically plants, nor are they entirely composed of protein. In fact, these ingredients come from a variety of sources and exist in multiple forms, including fresh/as-is, wet, and dry formats that range from whole products to fats, pastes, flours, concentrates, and isolates.

From a production, infrastructure, and cost basis, novel sources of ingredients (not limited to proteins) can be derived from three major categories: (1) plants, (2) microbial cells, including when used as hosts for recombinant protein production, and (3) animal cell cultivation. In plant-based meat formulation, animal cells are excluded, and therefore only involve one or a combination of plants, microbial cells, and recombinant proteins. For more information on novel ingredients involved in plant-based formulation, please read our article, [Formulating with Animal-Free Ingredients.]

Figure 2. Categories of Alternative Protein | Alternative protein products may incorporate one or a combination of novel proteins. Novel proteins can be segmented into three categories from a production, cost, and infrastructure perspective, but as they relate to plant-based meat, novel proteins may include one or a combination of those derived from plants, fungi, and microbial cell culture including recombinant proteins. Animal cell culture is excluded from plant-based meat products.

What is extrusion?

Extrusion transforms native ingredient biopolymers (inputs) into a continuous semi-solid (output). To complete this process, a screw system within a barrel conveys mass (a combination of dry ingredients, water, and/or oil) through a die (small opening). The mass is exposed to a combination of parameters, including heat, mechanical energy, pressure, and moisture.

The continuous fluid passes through the extruder according to its specific parameters, exits a die, and is cut into various lengths. Post-extrusion, the output is semi-solid and retains moisture. Wet Textured Vegetable Protein (TVP) output will go through marination, coating, and/or cooling steps. To create dry TVP, the product will pass directly from the extruder onto a conveyor, and then into a dryer (Guy 2003).

Process Flow Diagrams

Whole muscle meat products

Whole muscle plant-based meat resembles primary, whole muscle, animal-based meat. It displays a fibrous texture analogous to striated muscle. A product developer aiming to match the organoleptic properties of whole muscle products (such as a chicken breast, a pork chop, or a steak) may choose to use either dry or wet TVP formats. The decision will depend upon factors that include infrastructure capabilities, price point of the finished product, and level of preparation required of the customer. For example, a dry TVP may be ideal for food service environments that seek low-cost food solutions and have the capability to prepare the product for their customers. Likewise, a co-manufacturer may choose a dry TVP format if they are already equipped with infrastructure for low-moisture extrusion due to other dry products in their portfolio (such as cereal and puffed snacks).

Steps 1 - 7 below follow the figure 3 illustration, "Process flow diagram for whole muscle meat products" found on page 8.

Step 1: TVP

Textured Vegetable Protein (TVP) can be received in two formats:

Format 1: Dry TVP. This is generally processed using low-moisture twin-screw extrusion technology. Dry TVP is composed of pre-combined dry ingredients and water, and does not generally include fats during extrusion. Post-extrusion, it is passed through a dryer, packaged, and sold as a finished ingredient.

Format 2: Wet TVP. This is generally processed using high-moisture twin-screw extrusion technology. Wet TVP differs from dry TVP in the amount of water introduced during the extrusion process, the absence of a dryer post-extrusion, and the incorporation of fats alongside dry ingredients and water during extrusion.

Step 2: Hydration / Marination

Format 1: If TVP is received dry, it is combined with one or multiple ingredients, including heated water, broth, and/or fats. Once hydrated, it then may pass through a marination step. A marinade will typically incorporate fats, flavors, and functional additives—which serve a variety of functions to improve flavor, fat absorption, fat retention, and the ease of processing.

The term *functional additives* denotes ingredients designed primarily to impart a specific functional property (rather than nutritional value). An example of a functional additive in a marinade would be an emulsifier to ensure water and lipids don't separate, thereby ensuring uniformity throughout processing. Functional additives are typically used at low levels that do not significantly contribute to the product's nutritional content.

Format 2: If TVP is received wet, it has likely already incorporated fat content throughout its matrix. However, if more fat, additional flavoring systems, or specific functional properties are desired, wet TVP may pass through a marination step to incorporate these additional components.

Step 3: Coating

Regardless of format (dry or wet TVP), the product may be coated to incorporate additional flavor and texture. Coating may be a multi-step process requiring the addition of both an adhesive component and the desired exterior coatings, such as spices, flours, and bread crumbs.

Step 4: Cooking

Products designed to be reheat-ready (requiring minimal consumer preparation) are cooked following either the marination or coating step. Cooking uses various thermal processes such as frying, baking, boiling, and/or steaming.

Step 5: Extended Shelf-Life Processes (ESLP)

Extended shelf-life processes may follow consecutively—after marination, coating, or a cooking step—in order to prolong shelf life. ESLP may include thermal, non-thermal, or a combination of these processes (e.g., heat-pasteurization, high-pressure processing, UV, and the addition of antimicrobials).

Steps 6 - 7: Cooling, Packaging, & Storage

Cooling follows either cooking or ESLP steps and can include refrigeration, freezing, or a combination of these methods. By lowering the temperature, microorganism growth is inhibited, supporting a longer shelf life and reducing the risk of foodborne illness. Depending on a variety of factors—such as shelf-life requirements, customer uses, and placement within retail settings—producers can decide to refrigerate or freeze product and determine whether to conduct this step before or after packaging.

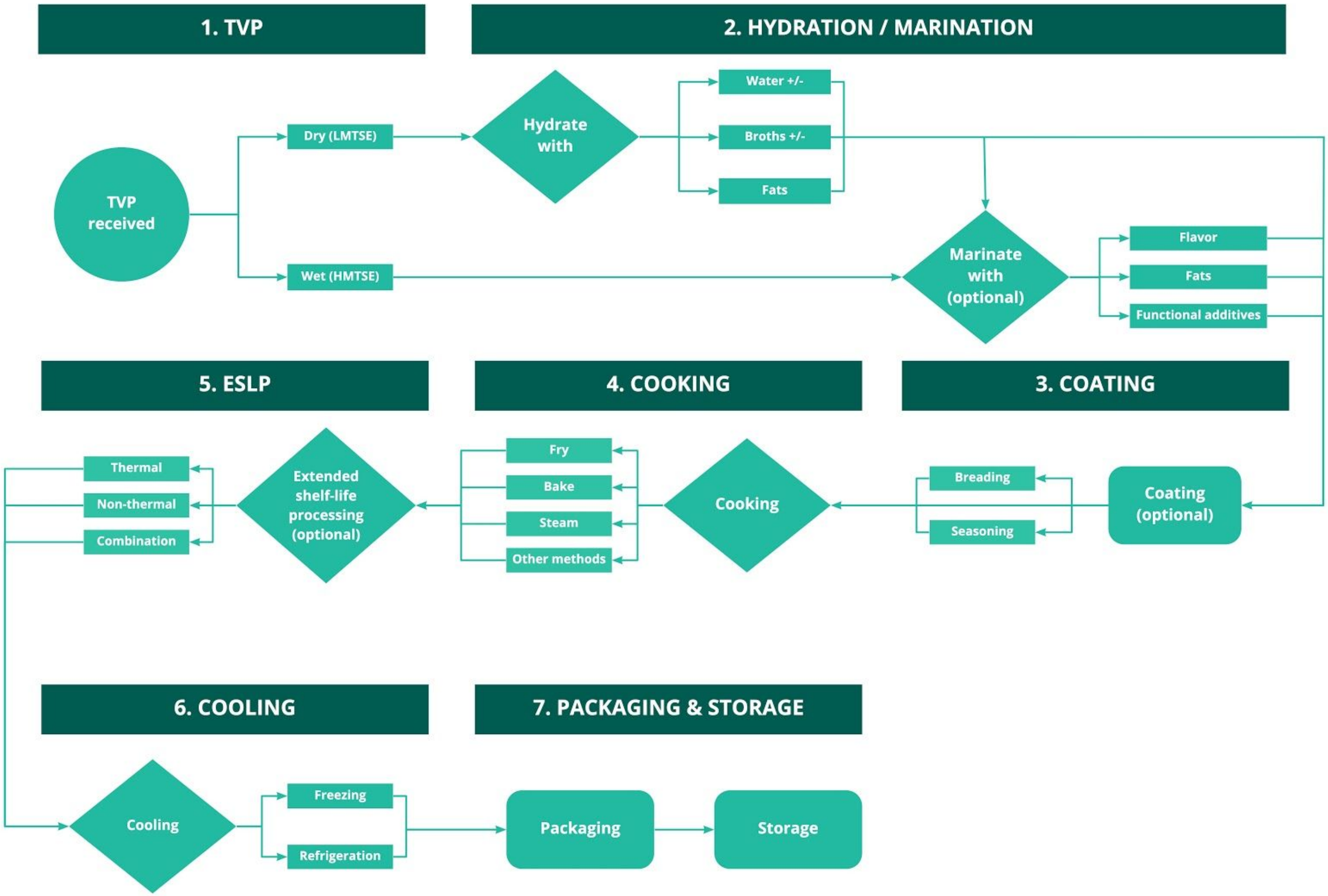

Figure 3. Process flow diagram for whole muscle meat products

Restructured meat products

Restructured plant-based meat products resemble ground, shredded, and bound animal-based meat products. They are often formed into patties, balls, nuggets, and sausage links and may include a casing, coating, and/or breading.

Steps 1 - 9 below follow the figure 4 illustration, "Process flow diagram for restructured meat products" found on page 11.

Step 1: TVP Hydration

TVP is received dry, generally having been previously processed using low-moisture twin-screw extrusion technology. TVP is mixed with heated water, broth, and/or fats.

Note: While TVP can be sourced as a finished ingredient from a manufacturer or supplier, it can also be created internally. If interested in learning to make TVP in-house, you will want to consider the additional resources made available in the appendix, such as the directories for continued learning and pilot-scale facilities.

Steps 2 -3: Ingredient Additions & Mixing

Other ingredients are combined with hydrated TVP and mixed to form a dough. Dough formation is composed of a ratio of macronutrients (proteins, fats, and carbohydrates), micronutrients (vitamins, minerals), flavors (spices, concentrated additives), and functional additives (to support such features as optimal texture, consistency, and shelf life) derived from plants, fungi, and/or microbial cell culture.

Step 4: Formation

The dDough is formed into various formats that may include patties, balls, nuggets, and sausage links.

Step 5: Coating

Following formation, both raw/fresh products (designed for the ready-to-cook market) and cooked products (designed to be reheat-ready and requiring minimal preparation) may be coated in seasoning, breading, and/or a sausage casing.

Step 6: Cooking

Products designed to be reheat-ready (requiring minimal consumer preparation) are cooked following either a dough formation or coating step. Cooking uses various thermal processes, such as frying, baking, boiling and/or steaming.

Step 7: Extended Shelf-Life Processes (ESLP)

Extended shelf-life processes may follow consecutively either after dough formation, coating, or a cooking step in order to prolong shelf life. ESLP may include either thermal, non-thermal, or a combination of these processes (e.g., heat-pasteurization, high-pressure processing, UV, and the addition of antimicrobials).

Step 8 - 9: Cooling, Packaging, & Storage

Cooling follows either cooking or ESLP steps and can include refrigeration, freezing, or a combination of these methods. By lowering the temperature, microorganism growth is inhibited, supporting a longer shelf life and reducing the risk of foodborne illness. Depending on a variety of factors—such as shelf-life requirements, customer uses, or placement within retail settings—producers can decide whether to refrigerate or freeze product and if this step will occur before or after packaging. Ambient cooling is also possible, but it may present a bottleneck in the production line and presents a higher food safety risk.

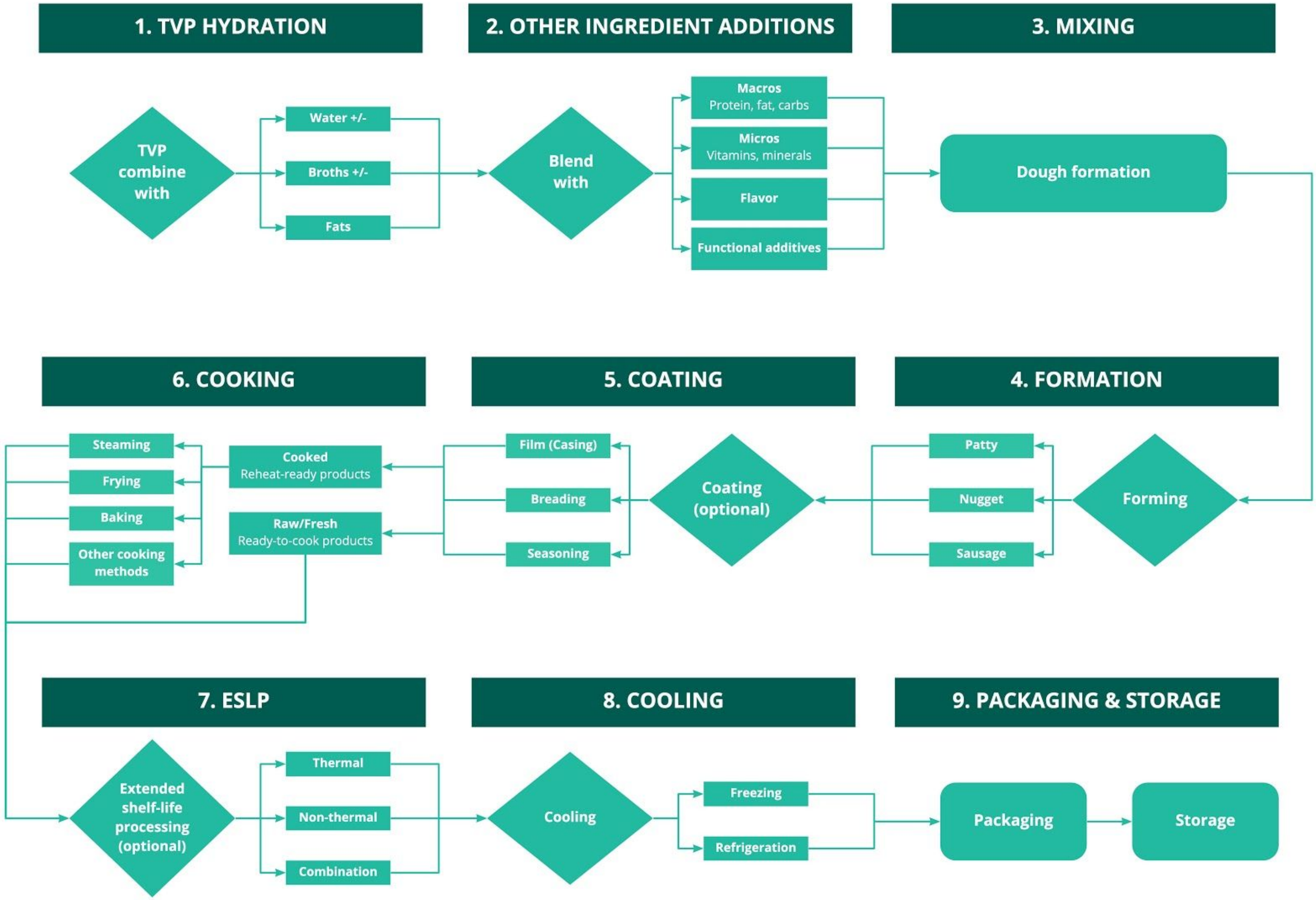

Figure 4. Process flow diagram for restructured meat products

Appendix

Glossary of terms

Alternative protein: Refers to one or a combination of plant, microbial, and animal cell culture-derived protein sources.

Cultivated meat: Meat derived from animal cells that are cultured through a variety of methods and combinations, which may include mixtures with recombinant proteins and/or plant proteins. Meat encompasses all animal tissue that is composed of cells derived from red meat, poultry, pork, seafood, and other animal sources. Sometimes referred to as 'clean meat' or 'cell-based meat.'

Extended shelf-life processes (ESLP): Processes that inactivate or eliminate certain microorganisms (bacteria, spores, enzymes, and others) responsible for the expiration of food products. Processes may include thermal, non-thermal, or a combination for the purpose of extending a product's shelf life (generally, post-pasteurization) (V. M. Balasubramaniam et al. 2016).

Extrusion: A technology platform that transforms native ingredient biopolymers (inputs) into a semi-solid continuous fluid (output) using heat, shear, pressure, and moisture. Utilized in the creation of dry and wet TVP, which is frequently utilized in plant-based meat products. Extrusion is a common technology used in the commercial production of cereal, puffed snacks, and pastas, among other foods.

Fermentation: Proteins derived from microbial cells, including fungi, algae, and bacteria sources that yield cells that are themselves the product, distinct from fractionated or isolated protein sources. Examples include whole forms of algae and fungi that may be in a dry, fresh, paste, or other format.

High-moisture twin-screw extrusion: An extrusion method utilized to yield products with a high moisture content, ranging from 40% to 70% (Osen and Schweiggert-Weisz 2016).

Low-moisture twin-screw extrusion: An extrusion method utilized to yield products requiring rehydration prior to consumption. Moisture content is less than 35% (Osen and Schweiggert-Weisz 2016).

Plant-based meat: Products that closely resemble the organoleptic experience of traditional animal-based meat using one or a combination of alternative protein ingredients.

Plant proteins: Proteins derived from plant ingredients, with "plant" defined by the domain Eukarya, kingdom Plantae. Examples include whole and fractionated forms of cereal, legume, and pulse ingredients.

Recombinant proteins: Proteins manufactured using fast-growing, highly efficient host microorganisms that have introduced genes encoding the desired protein(s). Examples include Impossible Foods' soy leghemoglobin protein and chymosin, a vegetarian rennet frequently used in cheesemaking. These proteins are extracted from the host and purified.

Restructured meat products: Products resembling ground, shredded, and bound animal-based meat products. They are often formed into patties, balls, nuggets, and sausage links and may include a casing or coating.

Textured vegetable protein (TVP): The wet or dry output of extrusion technology involving the input of dry ingredients, water, and/or lipids. TVP can be composed of one or a combination of plant-derived whole flours, concentrates, and isolates.

Whole muscle meat products: Products resembling primary, whole muscle, animal-based meat products. They display a fibrous texture analogous to striated muscle.

Directories for ingredients

Use these directories to find ingredients for your product formulations.

Online Directories
Food Ingredients First
Food Master
IFT Directories
Partner Slate
SupplySide Connect
UL Prospector

Directory of ingredient sourcing events

Event Name	Upcoming Event Date	Location	Size
IFT - National Annual Meeting	7/12/2020 - 7/15/2020	Chicago, IL (USA)	1,200+ exhibitors and 23,000 attendees
IFT-Section Suppliers' Night	Date, Location, and Size varies by IFT Section		
Supply Side East	4/21/2020 - 4/22/2020	Secaucus, NJ (USA)	250+ exhibitors and 3,500+

			attendees
Supply Side West	10/27/2020 - 10/30/2020	Las Vegas, NV (USA)	1,300+ exhibitors and 18,500+ attendees
SNAXPO	3/22/2020 - 3/24/2020	TBD (USA)	Low 100's exhibitors and low 1000's attendees

Directory of co-manufacturer events

Event Name & Website	Upcoming Event Date	Location
IPPE: International Production and Processing Expo	1/28/2020 - 1/30/2020	Atlanta, GA (USA)
Process Expo	TBD for 2020 10/8/2019 - 10/11/2019	Chicago, IL (USA)
PLMA Private Label Tradeshow - US	TBD for 2020 11/17/2019 - 11/19/2019	Chicago, IL (USA)
PLMA Private Label Tradeshow - International	5/26/2020 - 5/27/2020	Amsterdam, Netherlands (EUR)

These events offer co-manufacturer solutions, either in finding a co-manufacturer to produce a product or finding vendors to service co-manufacturers through equipment needs.

Directory of pilot-scale facilities (land grant universities)

Use this directory to find pilot-scale facilities in land grant university settings. This database houses facilities that advertise "pilot plant" and "extruder" or "extrusion" on their websites.

University Name	Extrusion Capabilities	Location
Kansas State University	Single-screw and Twin-screw extrusion	Manhattan, KS (USA)
University of Minnesota	Twin-screw extrusion	Saint Paul, MN (USA)
University of	Single-screw and	Lincoln, NE

Nebraska-Lincoln	Twin-screw extrusion	(USA)

To view our complete database of pilot-scale facilities at land grant universities, click here.

Directory of pilot-scale facilities (nonprofit and industry)

Use this directory to find pilot-scale facilities offered through nonprofit and industry innovation centers.

Facility Name	Location(s)
PacMoore Innovation Lab	Gridley, IL (USA)
Saskatchewan Food Industry Development Centre	Saskatoon, SK (Canada)
Wenger	Sabetha, Kansas (USA)

To view our complete database of pilot-scale facilities at nonprofit centers and in industry, click here.

Directory of co-manufacturers (production-scale facilities), consultants, & private labelers

Organization	Type	About
Brecks	Co-manufacturer	Experienced co-man with extrusion experience. Supplies plant-based meat products to Europe, North America and Asia.
Schouten	Private labeler	Schouten specializes in the development, production, and packaging of plant-based meats in all formats. Supplies 40+ countries, produced in Europe.
Sol Cuisine	Co-manufacturer, private labeler	Sol Cuisine produces non-GMO, gluten-free, kosher, halal and organic plant-based meat products. Supplies Canada & US.

To view our complete database of co-manufacturers, private labelers, and consultants with expressed interest or capability in producing plant-based meat, click here.

Directory for continued learning (classes)

Use this directory to find continued learning opportunities. This database houses short courses, workshops, online, and for-credit college courses related to extrusion.

To best use this resource, click the drop-down arrow per column to filter and sort information to your needs. Due to the time-sensitive nature of events, you may want to sort the "Date" in ascending order.

Course Title	Organizer	Upcoming Event Date	Type
Extrusion Workshops - Food	Buhler	4/21/2020 4/23/2020	Workshop
21st Annual Practical Short Course on Food Extrusion: Cereals, Pulses, Proteins & Other Ingredients	Texas A&M Engineering Experiment Station	TBD for 2020 9/29/2019 - 10/4/2019	Workshop
Leistritz Extrusion Academy BASIC	Leistritz	TBD for 2020 11/6/2019 - 11/8/2019	Workshop

To view our complete database of continued learning opportunities, click here.

Directory for continued learning (textbooks)

Book Title	Authors	ISBN (Hardcover)
Advances in Food Extrusion Technology	Medeni Maskan and Aylin Altan	978-1138199125
Extruders in Food Applications	Mian N. Riaz	978-1566767798
Extrusion Problems Solved: Food, Pet Food, and Feed	Main Ruiz and Galen J Rokey	978-1845696641
Extrusion Processing Technology: Food and Non-Food Biomaterials	Jean-Marie Bouvier and Osvaldo H. Campanella	978-1444338119

Don't see your organization listed here?

Or perhaps we're missing some opportunities you have found helpful? Please contact us to add your suggestions into one of our directories. The directories included in this resource are made freely available for the purpose of helping stakeholders accelerate and improve the production of plant-based meat.

If you have a **pilot- or production-scale facility**, or know of resources **for ingredient suppliers or manufacturers**, please complete this form.

References

Balasubramaniam, V. M., Yousef, A. E., Wan, J., & Husain, A. (2016, December). Kinder, Gentler Food Processing. Food Technology, 70(12), 20–28. Retrieved from < https://bit.ly/2K1QE4P>.

Guy, R. C. E., & . (2003). Extrusion Cooking. In *Encyclopedia of Food Sciences and Nutrition* (2nd ed., pp. 2222–2227). Elsevier Science Ltd. doi: 10.1016/B0-12-227055-X/00434-X

Osen, R., & Schweiggert-Weisz , U. (2016). High-moisture extrusion: meat analogues. In *Reference Module in Food Science* (pp. 1–6). Elsevier Inc. doi: 10.1016/B978-0-08-100596-5.03099-7

About the Authors

MJ Kinney
Food Scientist, The Good Food Institute
mkinney@gfi.org MJ Kinney at Linkedin

MJ works with leading food producers and manufacturers in the development of plant-based meat, egg, and dairy product innovations. MJ actively identifies obstacles in the alternative protein and product development space and works toward solutions that support their acceleration and sustainability. MJ holds a B.S. in Food Science and Human Nutrition from the University of Florida and joined GFI after several years of experience in R&D, technical sales, and project management in B2B and B2C industry settings.

Zak Weston
Foodservice Analyst, The Good Food Institute
zakw@gfi.org Zak Weston at Linkedin

Zak consults with leading foodservice operators and restaurant chains to help increase the quality and quantity of their plant-based offerings and meet the growing consumer demand for plant-based foods. Zak also works on projects to address supply-chain and production constraints, including conducting outreach to co-manufacturers. An active member of the Effective Altruism community, Zak holds a B.A. in Business Management from Cedarville University, and joined GFI after several years of experience in sales and working with startups.

JD Bauman
Corporate Engagement Intern, The Good Food Institute
Jbauman@hillsdale.edu JD Bauman at LinkedIn

JD works with GFI on projects addressing supply-chain and production constraints, including conducting research into plant-based meat manufacturing facilities and outreach to co-manufacturers. JD joined GFI while completing his studies in mathematics at Hillsdale College.

Acknowledgments

The Good Food Institute is a 501(c)(3) nonprofit organization. We are powered by philanthropy, relying on gifts and grants from our family of supporters to fulfill our mission.